PROCEEDINGS

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR

PROMOTING USEFUL KNOWLEDGE

VOLUME LIX

1920

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42.48

PROCEEDINGS

American Philosophical Society

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NULLO DISCRIMINE
MDCCXXVII

The American Philosophical Society

announces that an award will be made in the year 1921 of the

HENRY M. PHILLIPS PRIZE

The subject upon which essays are to be submitted is

> **The Control of the Foreign Relations of the United States :
> The Relative Rights, Duties, and Responsibilities of the President,
> of the Senate and the House, and of the Judiciary, in
> Theory and in Practice.**

The Essay shall contain not more than one hundred thousand words, exclusive of notes, and must be in the possession of the Society on or before December 31, 1920.

The Prize for the crowned essay will be Two Thousand Dollars, in gold coin of the United States, to be paid as soon as may be after the award.

Attention is called to the following regulations governing the award of the Prize:

Competitors for the prize shall affix to their essays some motto or name (not the proper name of the author, however) and when the essay is forwarded to the Society it shall be accompanied by a sealed envelope containing within the proper name and address of the author and on the outside thereof the motto or name adopted for the essay.

At a stated meeting of the Society in pursuance of the advertisement, all essays received up to that time shall be referred to a Committe of Judges, to consist of five persons, who shall be selected by the Society from nominations made by the Committee on the Henry M. Phillips Prize.

Essays may be written in any language, but, if not in English, must be accompanied by an English translation.

No essay which has been already published or printed, or for which the author has received any prize or profit of any nature whatsoever, shall be accepted in competition for the prize.

Essays must be typewritten on only one side of the paper, and six copies must be furnished by their respective authors for the use of the Committee of Judges.

The literary property of such essays shall be in their author, subject to the right of the Society to publish the crowned essay in its "Transactions" or "Proceedings."

The Society reserves the right not to award the prize if none of the competing essays is deemed worthy of it.

<div align="right">

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The essays must be sent, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A.

PROCEEDINGS

OF THE

AMERICAN PHILOSOPHICAL SOCIETY

HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

DETECTION OF SUBMARINES.

By HARVEY C. HAYES, Ph.D.

(Read April 26, 1919.)

OUTLINE.

1. Introduction:

    Research and development work carried out by two groups of scientists, one group backed by private companies, the other by the U. S. Navy.
2. Two general methods for detecting the presence of a body:

    a. Through energy radiated from the body.

    b. The presence of a field of force surrounding the body.
3. Both methods applicable to case of moving submarine.
4. First method most effective (radiated energy being sound), second method weak, due to limited range (field of force being magnetic).
5. Sound (physical characteristics).
6. Resonance and pressure type submarine receivers.
7. Types of submarine receivers:

    a. Acoustic.

    b. Microphonic.

    c. Magnetophone.

    d. Electrostatic Condenser.
8. Requirements for a perfect submarine detector.
9. Methods for determining direction:

    a. Maximum-minimum principle.

    b. Binaural principle.
10. Types of submarine detectors developed by:

    a. England—Mark I, Mark II, Mark I and Mark II, Nash Fish and Ryan Fish.

    b. France—Perrin Shielded Microphones and Walser Plate.

    c. United States—

        I. Submarine Signal Company.

            (1) Tuned Microphone.

            (2) Oscillator.

        II. General Electric Company.

            (1) C-Tube.

            (2) Three-Spot Devices:

INTRODUCTION.

The development of submarine detectors in this country started shortly after the United States entered the war. In April, 1917, the Submarine Signal Company, General Electric Company, and the Western Electric Company combined for the study of submarine detector apparatus and started a station at Nahant, Massachusetts. A foreign commission from France and Great Britain visited the United States in June, 1917, and laid before those most interested all the knowledge of submarine detection at that time in the hands of the French and the British. As a result of this visit, the United States Naval Experimental Station was started at New London, Connecticut, under the control of the United States Navy, and several physicists and engineers from different parts of the country were called together to carry on the research and development work at this station under the direction of the Special Board on Anti-Submarine Devices.

In the following paper no attempt has been made to give credit to individuals, but the developments brought about at the Naval Experimental Station and at the Nahant Station have been carefully stated in the hopes that proper credit may be given to each group of experimenters and in order that the excellent results accomplished by the United States Navy in this comparatively new field may be made known to the public.

GENERAL METHODS.

The presence of a body beyond our reach can be detected by intercepting some form of energy radiating from the body or through

the presence of some field of force surrounding the body. The first method promises detection at a greater range than the second since the intensity of radiant energy varies as the inverse square of the distance from the source while the strength of a field of force surrounding a polarized body varies as the inverse cube of the distance.

Both methods are applicable to the case of a moving submarine. The steel shell of the submarine must be surrounded by a magnetic field, due to polarization induced by the earth's magnetic field and also due to such permanent polarization as it may have taken on during construction. Also a certain amount of sound must radiate from the motors and propellers and other moving parts of the submarine.

Magnetic Methods Unsatisfactory Because of Limited Range.

The intensity of polarization which a submarine takes on through the action of the earth's magnetic field can be predicted with some accuracy and, as a result, the range at which it can be detected by magnetic methods foretold. Both theory and practice show this range to be about ⅔ the length of the submarine. This range, which is too slight to be helpful in searching or avoiding an operating submarine, is hardly sufficient for detecting any but the largest submarine when lying at rest on the bottom at maximum depth. No satisfactory method for determining the presence of a submarine lying at rest at considerable depth, say from 100 to 150 feet, has yet been perfected, but one or two promising methods are in the process of development.

Sound Methods Promise Greater Range.

Water is an excellent medium for transmitting sound. Its homogeneity and low viscosity makes the dissipation due to reflection, refraction, and transformation into heat comparatively slight.

The relation between intensity and distance is more favorable than that given by the inverse square law, because of the fact that the surface and bottom reflect the sounds and tend to keep them within two dimensional motion, much as the speaking tube confines sound to motion of one dimension. Because of this fact, sounds can be heard farther than they could if they were not confined.

A submarine sound having an amplitude of $\frac{1}{10}^{10}$ inches is near the limit of audibility. This represents a movement of the particles of the medium through a distance less than $\frac{1}{30}$ the diameter of the smallest atom.

The fact that water transmits sound energy with slight loss and that the relation between intensity and distance is more favorable than the inverse square law makes it appear reasonable that sounds can be heard at great distances in water if the energy of sound waves of such minute amplitude can be efficiently collected and brought to the ear.

General Nature of Sound.

Sound is a longitudinal wave motion having some vibrating body as a source. It travels through any material medium with a definite velocity depending upon the physical properties of the medium. The ratio of the velocity of sound in air to the velocity in water at a temperature of 60 degrees Fahr. is about $\frac{23}{100}$.

A sustained sound or tone has three physical characteristics: loudness, pitch and quality. Loudness or intensity depends upon the amplitude, (the distance the particles of the medium vibrate back and forth) : pitch, the highness or lowness of the tone, depends upon the frequency or number of waves which pass a fixed point per second ; quality depends upon the number and intensity of overtones or harmonics present in the sound. It is the quality of a sound that enables a listener to name the instrument upon which it is produced.

A sound which varies from moment to moment, as it does when produced by an engine or rotating propeller on a boat, has other characteristics, the most important of which is rhythm. Rhythm is more or less a characteristic of each type of boat. A trained listener can detect the faint rhythm of a distant boat through a mass of louder confusing noises and can tell the type of boat and judge its speed by the character and the period of the rhythm.

The general laws of reflection, refraction, and interference of light hold for sound, but there are certain practical differences because the wave-length of sound is much greater than the wave-length of light. As a result of this greater wave-length, sound has a greater tendency than light to bend around the edges of obstacles and not travel in straight lines. It results also from this that mir-

rors or lenses for altering the direction of sound must be very large, so large indeed that their use is impractical.

METHODS FOR COLLECTING SUBMARINE SOUND ENERGY.

There are two methods by which submarine sound energy can be efficiently brought to the ears. The first method makes use of the principle of resonance, the second method makes use of the difference in hydrostatic pressure between the dense and rare portions of a sound wave.

A tuned diaphragm in water can be thrown into violent agitation by a comparatively faint sound source if the frequency of the sound wave is the same as the natural period of the diaphragm. Calculation shows that in this way the diaphragm can be given an amplitude of vibration about 1,000 times the natural amplitude of the sound waves. And since the intensity of the sound from the diaphragm is proportional to the square of the amplitude this would result in multiplying the sound intensity given out by the diaphragm by something like one million. The Germans have made use of this principle in the listening gear installed on U-boats as also have the British in much of their earlier work.

A sound receiver operating on this principle can detect a submarine at a great distance providing the submarine gives out sound of the same frequency to which the receiver is tuned and also providing there are no other sound sources in the neighborhood giving out this same pitch.

An analysis of the sound emitted by a submarine shows a continuous sound spectrum throughout the range of the audible. No characteristic frequency is emitted. There is every reason to believe this is also true for all surface craft having a metallic hull and it follows that no distinct advantage is to be gained by using highly sensitive resonant receivers since the undesirable sounds, which are always more or less present, are intensified in the same proportion as the sound which it is desired to locate. Sensitivity alone, beyond a certain point ,is of no advantage and may prove to be a disadvantage.

The resonant receiver has two serious weaknesses. First, it only responds to sounds of one frequency, the natural frequency of its diaphragm. As a result all boats sound alike. The quality of their

sound is lost and, as has been stated, it is the quality of a sound that enables the listener to name the instrument on which it is produced. Secondly, resonant receivers do not faithfully reproduce phase and therefore are not well suited for use with devices operating on the binaural principle or which employ multiple receivers.

In this country emphasis has been laid on the development of non-resonant receivers. Such receivers are of the pressure type and though they are not so sensitive as the resonant type, and as a result can not give as great range when entirely free from disturbing noises, yet they do give a faithful reproduction of the sound thus making it possible for a trained listener to distinguish a submarine from other boats or water noises or noise from his own engines by the quality of the sound. Such receivers are suitable for use in binaural and multiple unit devices.

These receivers consist of a flexible chamber or a rigid chamber carrying a flexible diaphragm, preferably rubber. Since the volume of the receiver changes readily under variation of hydrostatic pressure, the water in the neighborhood of the receiver will be subject to less or greater pressure than at other points in the wave front, depending upon whether the volume change in the receiver is positive or negative. In order to establish pressure equilibrium the particles of the highly incompressible medium will be forced toward or from the receiver for a considerable distance beyond its surface. The receiver therefore absorbs the sound energy from a comparatively large volume of water which fact accounts for its rather high sensitivity.

Types of Submarine Receivers.

Five types of submarine receivers have thus far been developed. Plate I shows the principle of each of these five types.

The *Acoustic Receiver* consists of a flexible chamber connected through a tube to the ear. The walls of the chamber are made of rubber or thin metal.

The *Geophone* consists of two metallic plates between which is compressed a flexible rubber ring. The upper plate is made massive to give it inertia while the lower one is made lighter in order that its inertia may not seriously interfere with its motion. The intervening air space connects by tube through the inert plate to the ear. Such a

receiver when attached to the inside of the skin of a boat well below the water line is fairly sensitive to submarine sounds. The ordinary stethoscope is an example of the geophone.
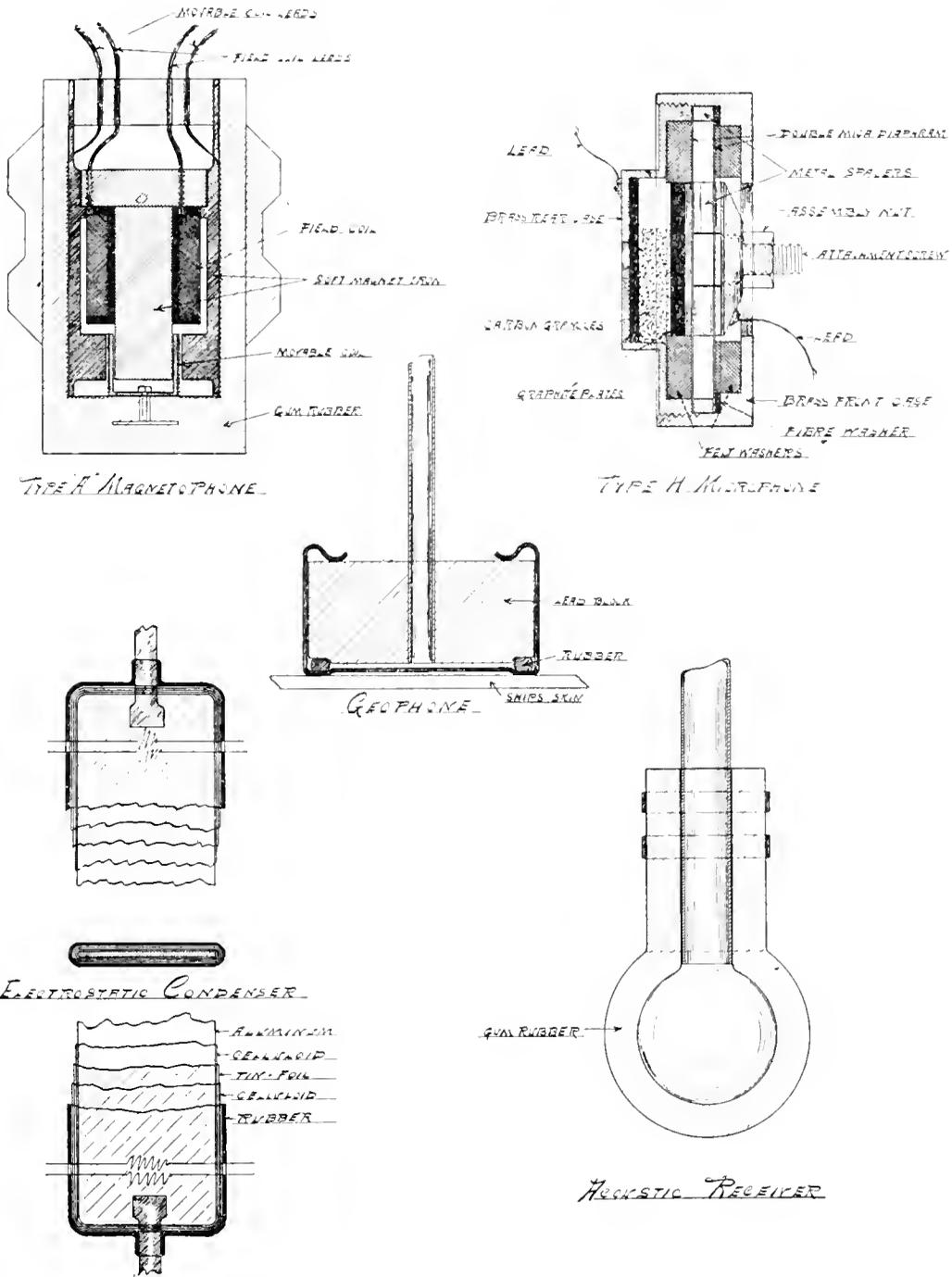
PLATE I. Types of submarine receivers.

The *Microphone* consists of two polished graphite plates placed parallel to one another and separated about $\frac{1}{16}$ of an inch. The

intervening space is partially filled with fine carbon granules. One plate is attached to a diaphragm which allows it to move back and forth along a line perpendicular to its surface, thus compressing and releasing the carbon granules. The cylindrical surface enclosing the space between the graphite electrodes must be made a non-conductor.

In operation the movable plate is rigidly attached to the inside of a diaphragm enclosing a water-tight space. Two electrical leads pass into the chamber through a water-tight stuffing-box and connect to the two plates respectively. The motion of the diaphragm produced by the sound waves causes corresponding changes in the pressure between the carbon granules, since the inertia of the body of the microphone is sufficient to prevent it from responding to the very rapid sound vibrations of the diaphragm. The electrical resistance through the microphone varies with the pressure between the carbon granules and therefore causes fluctuations in the electric current when a battery is connected across the microphone leads. These current fluctuations can be passed through a telephone and converted into sound at the listener's ear. In practice the telephone connection is made through a coupled circuit. Three types of coupled circuits which have been successfully used are shown in Plate IX.

The *Magnetphone* contains a movable coil of wire rigidly attached to the inside of a diaphragm enclosing a water-tight space. The leads from this coil pass from the chamber through a water-tight stuffing-box. The movable coil is placed in a radial magnetic field furnished by either a permanent or an electro-magnet. The vibration of the diaphragm causes the coil to cut across the lines of force, thereby generating electromotive forces which set up fluctuating currents through the coil when electric connection is made between the coil leads. These fluctuating currents can be passed through a telephone receiver and converted into sound at the listener's ear.

The *Electrostatic Condenser Detector* consists of a flat strip of metal, preferably aluminum, surrounded by a thin film of celluloid and this in turn surrounded by a layer of tin-foil. The whole is encased in rubber tubing, the ends of which are vulcanized so as to make the condenser water-proof. One rubber insulated electric lead

passes in through the rubber housing and attaches to the aluminum strip and a second lead in a similar way is attached to the tin-foil. These rubber-covered electric leads are both vulcanized to the rubber condenser-housing so as to give water-tight joints. The electric charge held by the condenser, when a battery is connected to the two leads, depends, among other things on the separation between the tin-foil and the aluminum strip. The variation in hydrostatic pressure in a submarine sound-wave causes this distance to vary slightly when the condenser is placed in the water, thereby producing slight current fluctuations through the battery and leads. These current fluctuations can be carried through a telephone receiver and converted into sound at the listener's ear.

The magnetophone and the electrostatic condenser give a more faithful reproduction of the sound than does the microphone, but they have the disadvantage of requiring an amplifier to increase their sensitivity. As a result only two types of receivers have been generally used—the microphone and the acoustic receivers.

REQUIREMENTS OF A SUBMARINE DETECTOR.

The requirements of a listening apparatus which embodies all that is desired may be stated as follows : It must be able to detect a submarine at considerable distance without interference. from noise produced by other shipping, or by wave noise, or by noise produced by the boat upon which it is installed. It should be able to give the distance and direction of the submarine accurately. It should be seaworthy, of robust mechanical construction, convenient and rapid of operation.

No instrument has been devised that satisfies all of these requirements. In fact no single instrument can give the distance of the submarine. The other requirements have been fairly satisfactorily met. These instruments are being continually improved, but even in their present state they give results far beyond what was considered probable or even possible at the time the developmental work was first started.

DETERMINATION OF DIRECTION.

Maximum and Minimum.—A submarine receiver can be made more sensitive to sound coming from certain directions with respect

to the orientation of the receiver than from other directions by
means of screening, etc. By rotating such a receiver about a ver-
tical axis, the direction of a sound source can be roughly determined
by judging the position of the receiver for maximum or minimum
sound intensity. Such a receiver is shown in principle in Fig. 1,
Plate II. The receiver, represented by the small circle, is placed
within a heavy lead cone. The English have utilized this principle
in all of their listening devices.

Binaural Principle.—Experiment proves that the direction of a
sound can not be judged with any degree of accuracy by one ear
alone, unless the pitch of the sound is fairly high (above 800 or
1000), but by using both ears the listener can locate the direction
with considerable accuracy for any pitch within the range of the
audible and the accuracy proves to be greatest when the direction
of the sound is about normal to a line joining the two ears.

Suppose the sound source is to the right of the listener. The
sound received by the left ear will differ in two respects from that
received by the right ear. First, the left ear receives the sound later
than does the right ear and secondly, the intensity of the sound is
somewhat less in the left ear because of the sound shadow cast by
the head. The difference of intensity in the two ears is very slight
for sounds of low frequency but becomes greater as the pitch is
raised, due to the fact that the dimensions of the head are such that
it only serves as an efficient screen for sounds of short wave-length.
A single ear therefore becomes a screened receiver for high pitch
sounds. The determination of direction, when both ears are used,
depends largely on the difference in the time between reception at
the two ears. This is especially true for sounds of low frequency,
although the fact that intensity is slightly different at the two ears
may also be of some help. Whenever a sound reaches the two ears
at the same time, it appears to come from a direction perpendicular
to the line joining the ears and the listener judges the sound to be
somewhere in the plane which is the perpendicular bisector of this
line. If the sound source is to the right of this plane, the sound
reaches the right ear first and the listener judges the sound to come
from this direction. Sound is judged as coming from the right or
left, depending whether it reaches the right or left ear first re-
spectively.

It is evident that the difference in time of reception at the two ears varies most rapidly, as the head is turned from a direction normal to a line joining the two ears and for this reason the listener can judge this direction with greatest accuracy.

This so-called "binaural principle" for determining the direction of sound is not new. It has been used for determining the direction of sounds in air, and was early recognized and tested by the British for determining the direction of sounds in water. These tests were unsatisfactory mostly for the reason that the apparatus was not properly designed. All the listening devices developed in this country make use of this principle for determining direction.

The direction of a submarine sound can be readily determined if two like receivers (one connected to each ear of the listener) are attached to a horizontal arm which can be rotated about a vertical axis. In general, sound will not strike both receivers simultaneously and as a result the impulses will not reach the listener's ears at the same instant. Suppose the sound impulse reaches the listener's right ear first, then the sound will appear to come from the right in accordance with the binaural sense, and if the path by which the sound travels from the submarine receiver to the ear is the same for both receivers, it must follow that the direction of the sound source is along a perpendicular to the arm carrying the two receivers when this arm is so oriented that the impulses reach the two ears in phase.

A consideration of Fig. 2, Plate II., shows that the sound would appear to be centered, were it coming from the direction given by either of the arrows 1 or 2. This ambiguity in direction of 180 degrees can be removed by rotating the two receivers from the position marked L and R to the position marked L' and R'. Let us suppose that the receiver marked R attaches to the right ear and the one lettered L attaches to the left ear. With the receivers in this second position, if the sound comes from the direction given by arrow 1, it would appear to the listener to come from his right since it would reach the right ear first. If, however, the sound should come from the direction marked by arrow 2, it would appear to the listener to come from his left since it would reach his left ear first. The ambiguity in direction can therefore be removed by rotating the receivers somewhat from the position in which the sound appears to be

centered and noting whether this shifts the apparent direction to the right or to the left.

The rule which is generally followed in determining the direction of a sound by a rotating device operating on the binaural principle is as follows: If the sound appears to come from the right, rotate the receivers in a clockwise direction until the sound appears

SHIELDED RECEIVER

FIG. I.

FIG. II.

FIG. III.
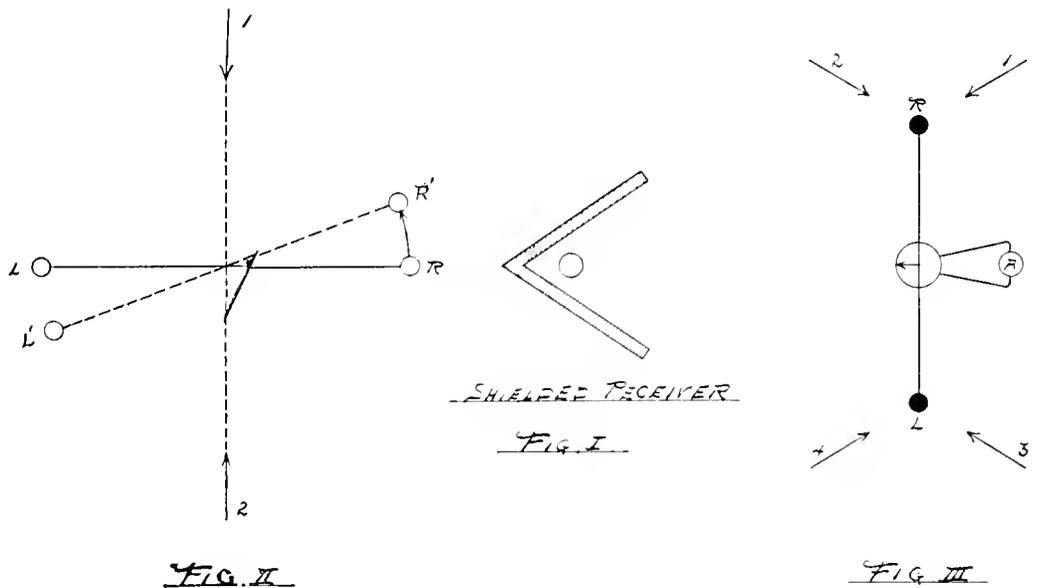
Plate II.   Methods for determining direction.

to be centered. If the sound appears to come from the left, rotate the receivers in an anti-clockwise direction until the sound appears to be centered.

A consideration of Fig. 3, Plate II., shows that this rule is general. Suppose the sound is coming from the direction of arrow 1, it evidently strikes the right receiver first and would appear to the listener to come from his right. Rotating the receivers in a clockwise direction will at first increase the length of time between the arrival of the sound at the two ears but a continuation of the rotation will decrease this time difference in arrival until finally when sound appears binaurally centered the small arrow at the center of the line joining the two receivers will point in the direction of the sound. If the sound comes from the direction represented by arrow 2, it is evident that a clockwise rotation would be employed and when the sound is binaurally centered the arrow will point its direction. In case the sound is coming from the direction represented by

either arrow 3 or arrow 4 it reaches the left ear first and will there-
fore appear to the listener to come from his left. It is readily seen
from the diagram that a rotation of the receivers in an anti-clock-
wise direction will make the sound appear binaurally centered when
the small arrow at the center of the line of receivers points in the
direction of these sounds respectively.

In order to make this rule effective, the importance of attaching
the proper receiver to the proper ear is obvious.

A device that depends upon rotation for determining direction
has two distinct disadvantages: first, it cannot be operated when the
boat is running and second, it must be lowered before taking a
bearing and hoisted before the boat can again get under way, thus
causing considerable labor and loss of time. This defect was early
recognized and overcome by the workers at the Naval Experimental
Station who developed a method whereby the binaural principle for
determining direction could be employed without the inconvenience
of rotating the two receivers. This development opened up a wide
field for research which has resulted in the most serviceable types
of submarine detectors.

The Principle of Binaural Compensation is readily understood
by referring to Fig. 1, Plate III. Suppose the two receivers R and
L are connected to the right and left ear respectively and sound
comes from the direction indicated by arrow 1. This sound reaches
R first and as a result appears to the listener to be located on his
right. If the tube leading to the right ear is lengthened by an
amount equal to $\frac{23}{100}$ the distance from R to C, the impulses from
receiver R will be delayed so that the impulses from both receivers
reach their respective ears simultaneously and the sound will appear
to the listener to be binaurally centered. The same result could
obviously be accomplished by shortening the sound path to the left
ear or by lengthening the path from R half the amount and at the
same time shortening the path L by the same amount, the only re-
quirement for binaural centering being that *the path difference* be
made equal to $\frac{23}{100}$ of the distance R to C ($\frac{23}{100}$ being the ratio of
the velocity of sound in air to the velocity in water).

The path difference between the two receivers is directly de-
pendent on the angular separation between the line of the receivers

and the direction of the sound. This relation between the path **dif-**
ference and the direction of the sound is readily seen to be:

$$d = 0.23\ a \sin\theta,$$

where d represents the path difference in air, a the distance between
the two receivers, and θ the angle the sound makes with the line
joining the two receivers.

Since this definite relation exists between path difference and
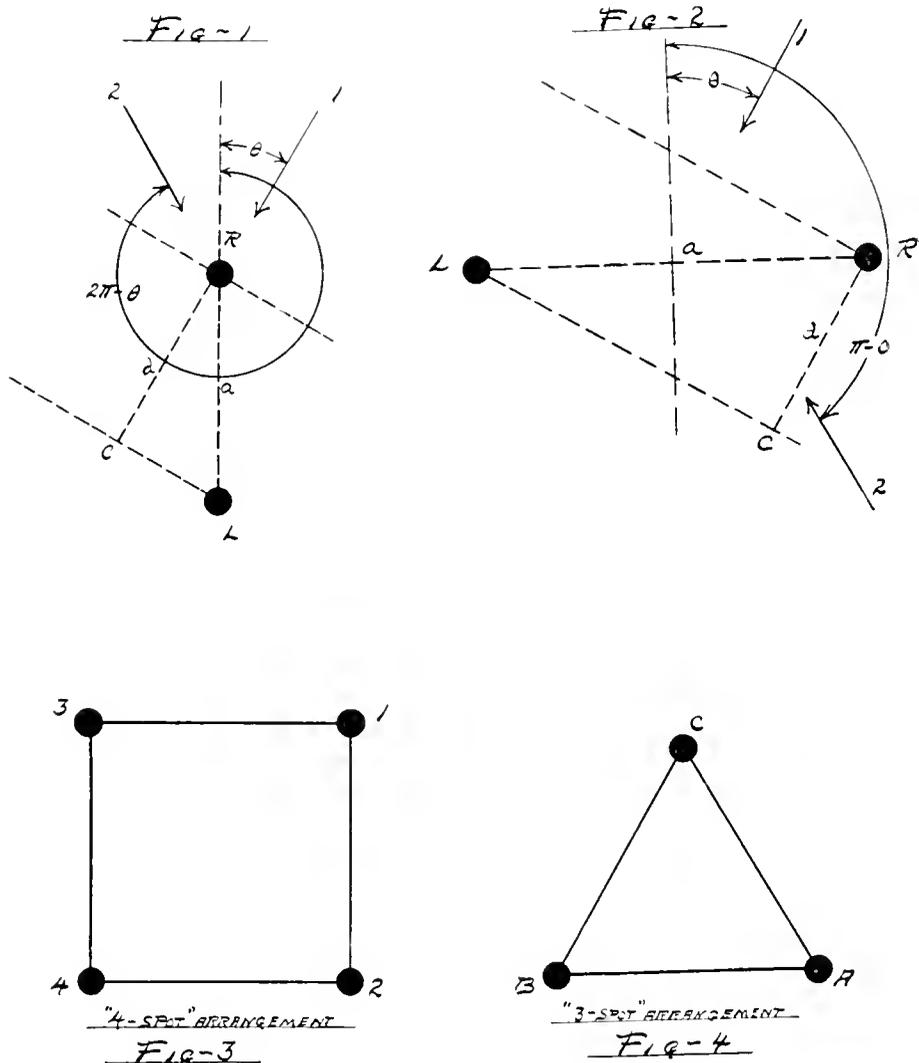
PLATE III. Principle of binaural compensation.

the direction of the sound, a device for varying the air paths can **be**
introduced and calibrated directly in terms of angle.

Two weaknesses in this method for determining direction are
apparent. First, if the angle approaches zero or 180 degrees a large

variation in angle requires but slight change in air path and as a result a very slight error in determining the difference d in air path lengths will result in a large error in determining the angle. Secondly, the direction so determined will be ambiguous.

Fig. 1 shows that the time difference between the reception of the sound at receivers R and L will, from conditions of symmetry, be the same whether the sound comes from the direction indicated by arrow 1 or that indicated by arrow 2. It is, then, impossible to tell from the value of d whether the sound comes from the direction of θ or from the direction $2\pi-\theta$.

Both of these weaknesses are readily overcome, as will be seen by a consideration of Fig. 2, Plate III. Suppose the line connecting the two receivers R and L is perpendicular to the direction from which θ is measured and suppose the sound is proceeding from the same angle θ that is represented by arrow 1 in Fig. 1. The time difference between the reception of the sound at the two receivers R and L is represented by the water path R–C, Fig. 2. But sound proceeding from the direction represented by arrow 2, would, from conditions of symmetry, give a time interval between reception at the two receivers represented by the same length of water path. It will be impossible then to tell from the value of d whether the sound comes from the direction θ or $\pi-\theta$.

The direction of the sound as determined by two receivers oriented as in Fig. 1 is determined as being either θ or $2\pi-\theta$ while the direction as determined from a pair of receivers oriented as in Fig. 2 is determined as θ or $\pi-\theta$. It must follow that the angle common to the two determinations, viz., θ, gives the true direction and thus the ambiguity is removed. Moreover, it is to be noticed that the angular range within which the determination of direction is subject to most error when the two receivers are oriented as in Fig. 1 is the region wherein direction is determined with greatest accuracy when the receivers are oriented as in Fig. 2. It therefore becomes possible to determine direction accurately at all angles provided that reliance is placed on the proper pair of receivers.

The line connecting the second pair of receivers need not necessarily be at right angles to that connecting the first pair, and the second pair of receivers may utilize one receiver of the first pair.

The minimum number of receivers is three. All of the listening de-
vices developed at the Nahant Station except the C-Tube, make use
of three receivers located at the vertices of an equilateral or isosceles
triangle. Such a device is often called a " 3-Spot." Devices of this
character developed at the Naval Experimental Station employ four
detectors located at the four corners of a square. Such devices are
commonly named " 4-Spots." The " 4-Spot " can still be operated
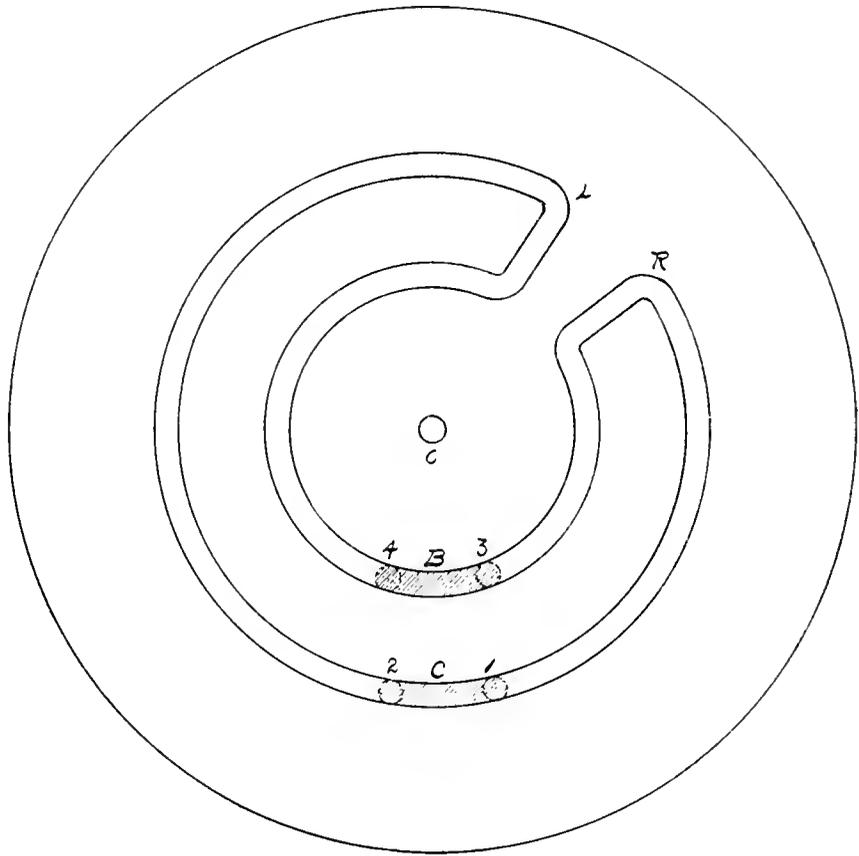
PLATE IV. Diagram of double-groove compensator.

if any one receiver becomes damaged but the " 3-Spot " becomes use-
less under such conditions.

An instrument called a *compensator* has been developed by which
the path difference between the two receivers and the ears can be
varied. Compensators are made in various forms for different spe-
cial purposes. Plate IV. shows the principle of one of the simplest
forms. It consists of an upper brass casting with grooves as shown
by the full lines. This casting seats on a lower brass plate upon
which it can be rotated about a central pivot (*o*). The lower plate

carries two projecting blocks carefully formed to give a sliding fit in the grooves of the upper plate. The lower plate is perforated by four holes, numbered 1, 2, 3, and 4 in the figure, which open respectively through the ends of the two blocks B and C. Thus two con-
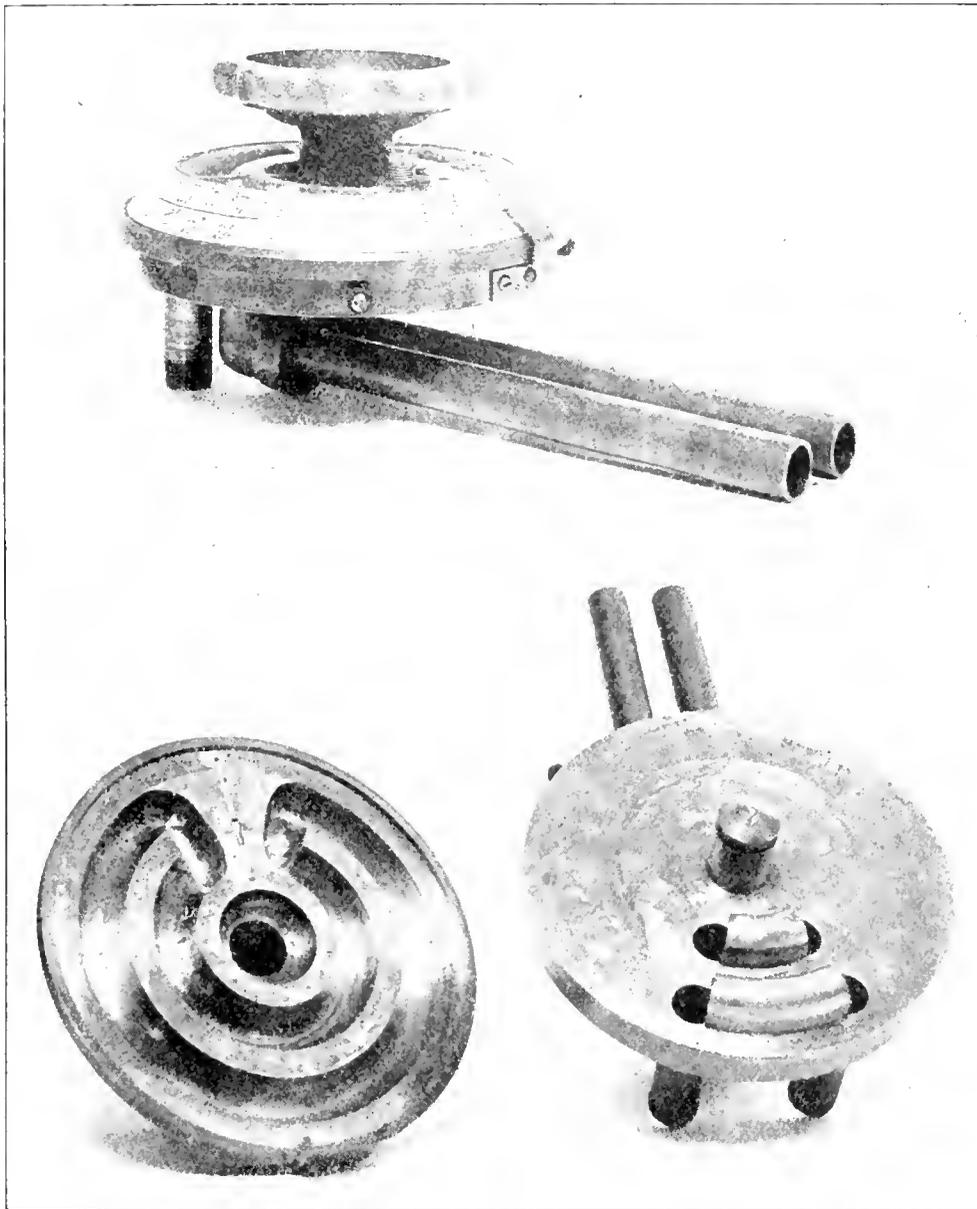
PLATE IV. *a.* Double-groove binaural compensator.

tinuous air-paths traverse the compensator, one connecting from 1 to 3 through that part of the groove marked R and the other connecting from 2 to 4 through the other part of the groove marked L. By rotating the top plate the difference in the length of the two air-paths can be varied at will up to the capacity of the compensator.

In operation each path through the compensator is connected in series with one of the two paths leading from the receivers to the ears, care being taken that the path lengths outside of the compensator are equal. Any sound striking the two receivers can be binaturally centered by turning the compensator to a position such that the impulses from the two receivers reach the ears simultaneously. The high development of the binaural sense may be appreciated from the fact that an untrained listener can make a compensator setting accurate to within 10^{-5} seconds while a trained listener can do better than 5×10^{-6} seconds.

The compensator is provided with a special switching device by which different pairs of receivers can readily be connected through the compensator. The movable plate of the compensator carries four scales arranged in pairs, each pair referring to a definite set of receivers. The scales are arranged in pairs because of the ambiguity in direction at each setting of the compensator. The direction of a sound source is determined by making a binaural setting on one pair of receivers and noting the two angles on the double scale belonging to this set of receivers. Then throw the switch so as to connect in the second set of receivers and make a second binaural setting and note the two angles given by the double scale which refers to this second set of receivers. The common angle on the two settings gives the direction. Due to errors in setting the common angle will in general not give perfect agreement, and the angle is taken from the scale least subject to errors for the angle in question. In Plate IV. *a*, Figs. 1 and 2 show the Type T compensator assembled and dissembled respectively.

Submarine Detectors Developed in England.

The principle of the English listening devices is shown in Plate V. The *Mark* I. consists of a tuned diaphragm mounted within a somewhat massive ring carrying a microphone within a small rigid watertight housing at the center of the diaphragm. One side of the diaphragm is screened by a heavy plate. This receiver is highly resonant and is most sensitive to sounds coming from the side opposite to the screen. The receiver is rotated in the water and the direction is determined by the maximum-minimum principle, and since

neither the maximum nor minimum is well defined it is impossible to determine direction with any degree of accuracy.

The *Mark* II. receiver is very similar to the Mark I. except that it carries no sound screen. It is equally sensitive to sounds striking

Mark I   *Mark II*

Mark I + Mark II

Nash Fish
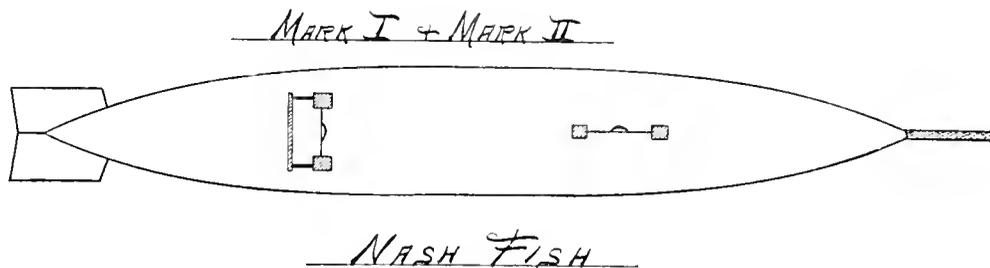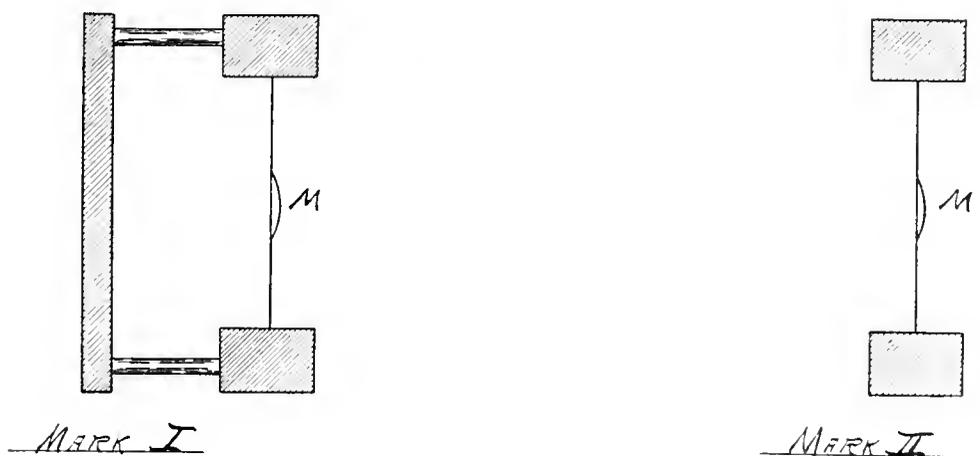
PLATE V. Principle of English listening devices.

either side of the diaphragm. Thus there are two positions for the receiver where the sound intensity will be at a maximum and neither of these positions is sharply defined. A sound proceeding in a direction parallel to the diaphragm affects the two sides equally and in opposite sense so there is no motion of the diaphragm and the intensity of the received sound is practically zero. This minimum position is very sharply defined and will determine the direction of a sound with high accuracy except for an ambiguity of 180 degrees.

In the *Nash Fish* and certain submarine installations both the Mark I. and the Mark II. are used, the line of direction being determined by the minimum setting on the Mark II. and the ambiguity being removed by the Mark I. These installations, especially the Nash Fish, are complicated due to the fact that remote control

motors are required to rotate the receivers. They are also subject
to the defects which are inherent in resonance receivers, viz., their
sound response is devoid of quality and their operation is strongly
interfered with by local noises and noises from neighboring shipping.

SUBMARINE DETECTORS DEVELOPED BY THE FRENCH.

Two types of submarine detectors have been developed by the
French—the "Perrin Microphone" and "The Walser Plate." The
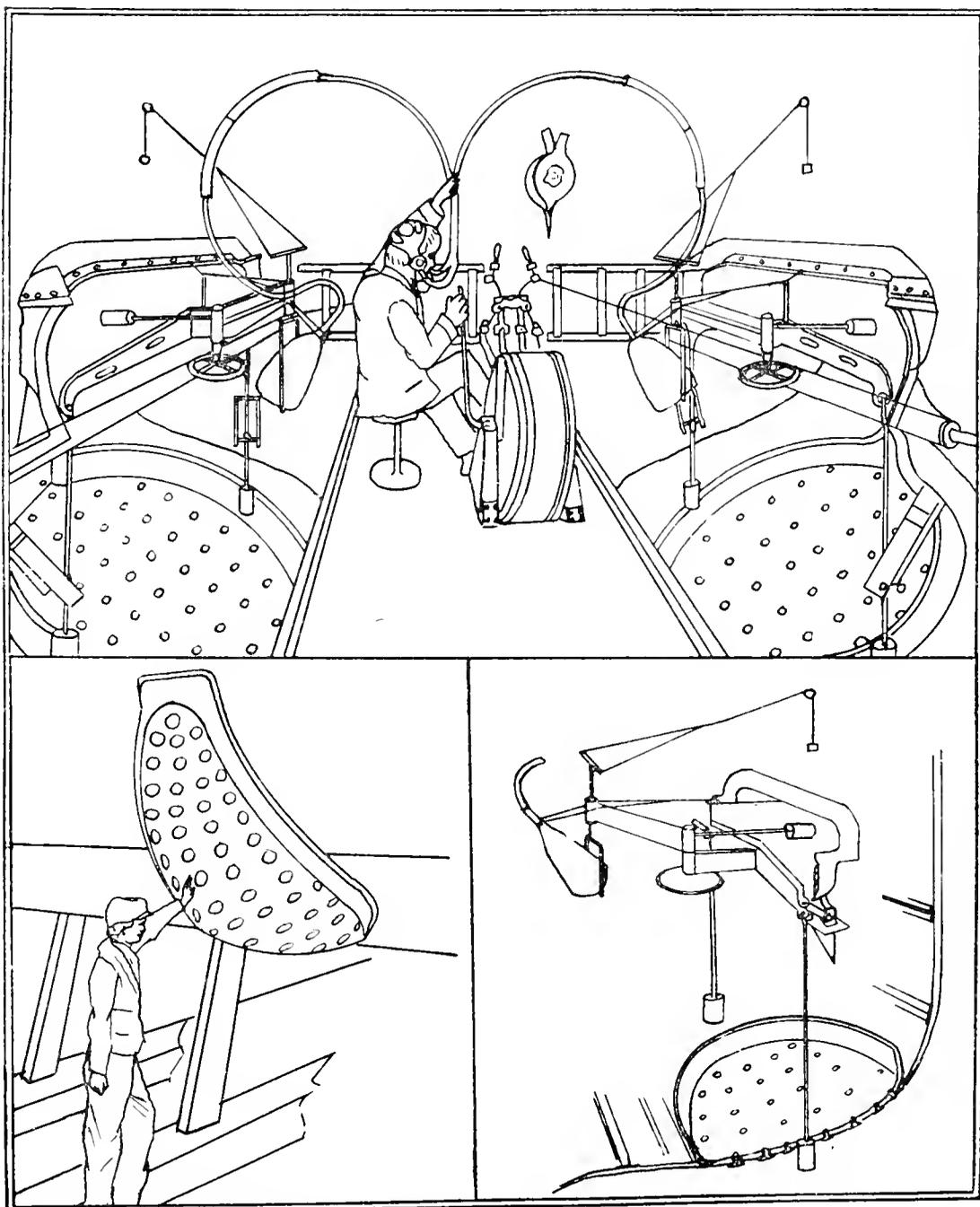
PLATE VI.   Installation of Walzer Plate (sound lens) apparatus.

Perrin Microphone, see Fig. 1, Plate II., consists of a sensitive microphone mounted within a massive conical-shaped shield. Like the Mark I. it determines direction by the maximum-minimum principle and is not capable of giving accurate bearings for the reason that neither the maximum nor minimum is well defined.

Some idea of the construction and operation of the *Walser Plate* detector can be gained from Plate VI. The plate proper forms a portion of the ship's skin. The surface is convex outward, the curvature being such that a sound wave passing from the water through the plate is brought to a focus within the boat. The plate is perforated with numerous holes, each of which is closed by a thin metal diaphragm, in order that the sound may pass more freely. One such plate is installed on each side of the boat.

Each plate really serves as a sound lens and the direction of the sound source is determined from the position of the sound focus within the ship. The position of this focus is located by means of a movable trumpet which connects with the listener's ears. The framework upon which the trumpet arm is pivoted is suspended fore and aft on gimbals and counterbalanced so that the trumpet remains in the same horizontal plane that contains the focus.

In many respects the Walser Plate is a superior device. Due to its focusing effect the disturbance from local and other undesirable sounds is greatly reduced while desirable sounds are concentrated and intensified. The device can be operated while moving at considerable speed and good results both as regards range and bearing are claimed. It has, however, the double disadvantage that it is expensive and difficult to install. In fact its dimensions are such that it cannot be installed on many types of boats.

Submarine Detectors Developed in the United States.

Plate VII. shows the principle of two types of submarine sound detectors which were developed by the Submarine Signal Company for locating submarine bell signals installed on light-ships. Each of the small tanks attached to the ship's skin carries a *microphone receiver tuned to the submarine bells*. These microphones each connect with a single telephone receiver on the ship's bridge. These tanks are filled with oil or water. By comparing the intensity of a

sound as received in the two phones its source can be located as to
port or starboard. By swinging the boat until the intensity is the
same in both phones the direction of the sound can be somewhat ac-
curately located as dead ahead.
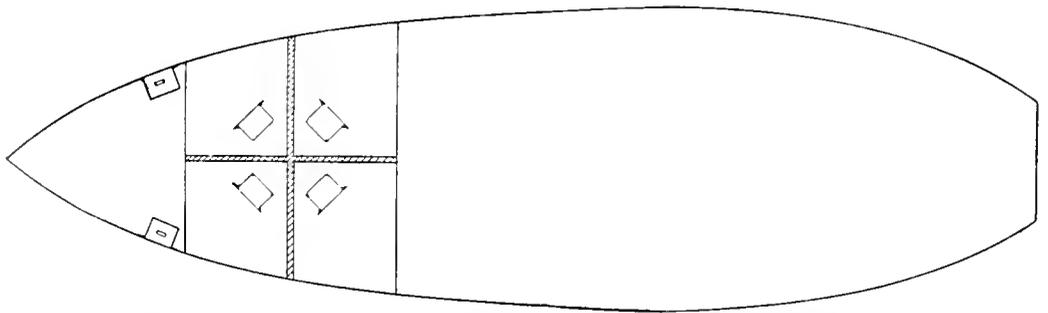
PLATE VII. Hydrophone installation of Submarine Signal Company.

The second installation consists of four *Fessenden oscillators*
placed one in each of the four quadrants of a large tank within the
ship. Each quadrant is separated from the others by a sound-screen.
By comparing the intensity of sound as received on each of the four
oscillators the direction of the sound source can be located to within
90 degrees.

Detector installations were early developed at both the Naval
Experimental and the Nahant Stations that were superior both as to
range and bearing accuracy and the above named devices were aban-
doned.

Two types of detectors have been developed at the Nahant Sta-
tion—the " C-Tube " and the " 3-Spot." One type, the C-Tube, has
been partially explained. It consists of two rubber acoustic receivers
spaced about four feet apart on a horizontal arm which can be
rotated about a vertical axis. Each receiver connects to one ear re-
spectively through metal tubes ending in stethoscope leads. The
direction of a sound is determined by the binaural principle in a
manner that has been described.

The C-Tube is a superior detector device. It is capable of giv-
ing good range and accurate angular bearings, but its operation is
seriously interfered with by local noises and noises from neighboring
shipping and it cannot be operated while the boat is moving. More-
over, it must be lowered before taking a bearing and must be raised

before the boat can get under way. Plate VIII. *a* shows one form
of the C-Tube developed at Nahant. (See page 30.)

The "3-Spot" detector operates on the principle of binaural
compensation and was developed soon after this principle was estab-
lished at the Naval Experimental Station. An improved type of
microphonic submarine receiver called a "rat" was developed which
proved highly sensitive, non-resonant, and durable. The construc-
tion is shown in Plate VIII. *b*. The microphone is carried by a rubber
diaphragm which encloses a water-tight space housing the micro-
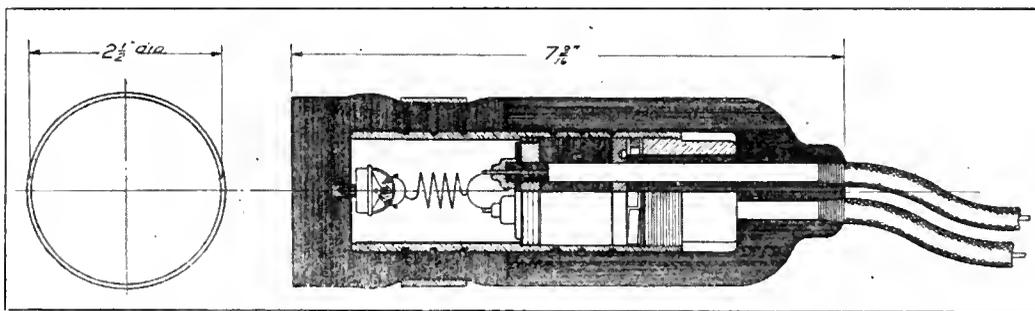
PLATE VIII. *b*.   The microphone housing or "rat," developed by the General
Electric Company for "3-Spot" detectors.

phone. The leads to the microphone pass through a water-tight
stuffing-box at the end of the cylindrical shaped chamber opposite to
the diaphragm. Three of these receivers are fixed in position at the
vertices of an equilateral triangle four feet on a side. One lead
from each microphone attaches to a common lead into which a bat-
tery is connected in series. The other three leads, one from each re-
ceiver, pass through small inductance coils and thence to the com-
mon. A special type of telephone receiver connected in series with
a condenser is shunted across the inductance. This wiring scheme
is shown in Fig. 1, Plate IX. Figs. 2 and 3 show other schemes used
for connecting in the telephone which are employed in devices de-
veloped at the Naval Experimental Station.

The two telephone receivers are attached respectively to the two
inlets to the compensator so that the sound is required to pass
through the compensator and the stethoscope leads before reaching
the ears.

A neatly designed switch arrangement makes it possible to con-

nect either one of the three pairs of microphone receivers to the two
telephone receivers so that not only can the ambiguity in direction be
removed, but a pair of receivers favorably oriented for accurate de-
termination of direction can be used.
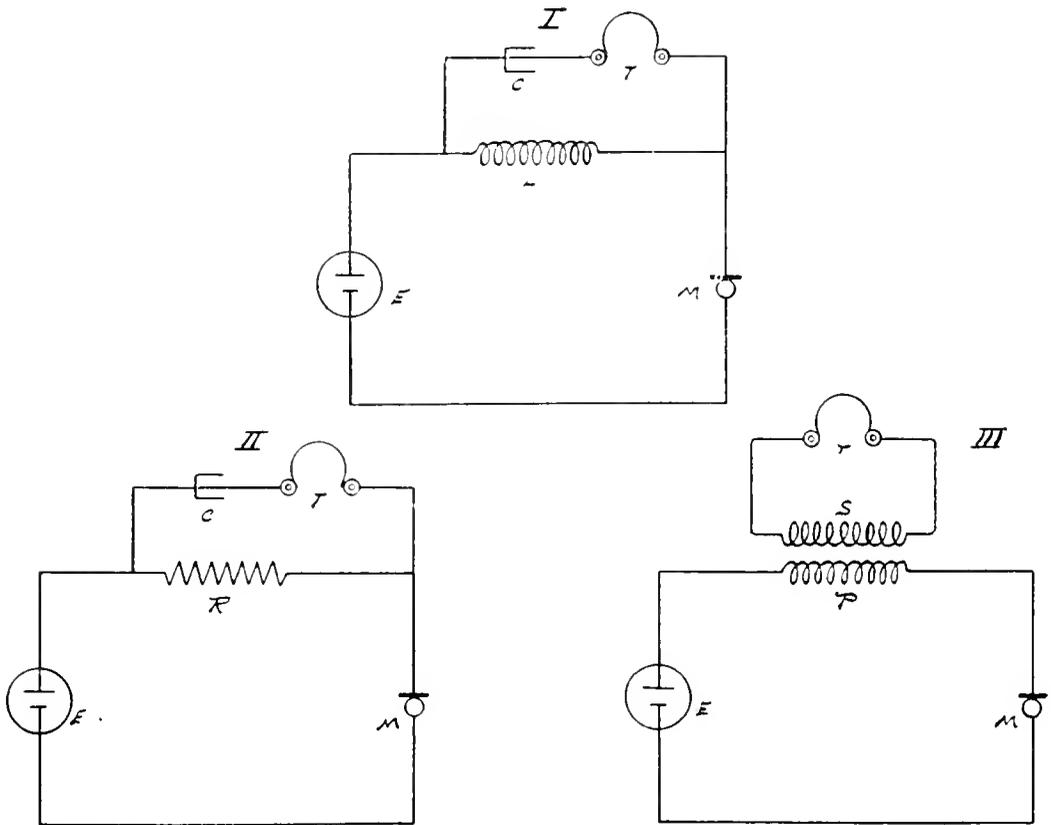
PLATE IX.　Types of microphone circuit.

This triangular arrangement has been mounted in several dif-
ferent ways to meet special conditions. When the three " rats " are
mounted on a light frame suspended from a float for use as a drifter
set it is termed a " K-Tube "; when mounted on a streamline frame
attached to the deck or keel of a submarine it is called a Y-Tube:
when mounted suitably for suspending beneath a light-ship it is
termed an " X-Tube "; when mounted within a tank inside the ship's
skin it is termed a " Delta-Tube "; and when arranged for towing
behind a moving boat it is called an " OS-Tube," or an " OV-Tube,"
or an " OK-Tube " depending upon its form.

The " 3-Spot " in all its forms is an excellent listening device. It
is durable, easy to install, determines bearing with considerable ac-

curacy, is simple and rapid in operation, and is capable of giving long range *if there are no disturbing noises present.*

The chief difficulty in submarine detection by sound lies in the fact that under normal operating conditions the detecting apparatus is mounted in the midst of numerous sound sources such as propeller and machinery noises on the listening boat, breaking of waves and slapping of waves on the boat, noises from promiscuous shipping, etc. The range at which a submarine can be detected is largely dependent on the ratio of the intensity of the sound from the submarine as compared with that from other sources. Increasing the sensitiveness of the receivers beyond a certain limit is of no advantage since the disturbing noises are magnified in the same proportion as are the sounds from the submarine.

Under such circumstances it becomes necessary to devise an instrument that will magnify the sound coming from a definite direction without correspondingly magnifying sounds from other directions.

This result can be accomplished by using sound lenses or mirrors, an example of which is the " Walser Plate," but because of the length of sound waves in water their area must be so great, if they are to give a marked advantage that their use is practically prohibited. As soon as the principle of compensation was recognized it became evident that instead of a single receiver connecting with each ear it would be advantageous to have several receivers spaced some distance apart, provided a compensator could be devised that would not only make it possible to binaurally center the composite sound reaching each ear from its respective group of receivers but at the same time would compensate the separate air paths to the individual receivers so that the sound response from all would arrive at the listener's ears in phase. By properly adjusting such a compensator the response from the several receivers to sound from any particular direction could be brought to the listener's ears in phase and since under these conditions the intensity of the sound will be equal to the sum of the intensities from the several receivers the sound reception from this particular direction will be magnified.

It is evident that for this same setting of the compensator the response from the several receivers to sound from any other direc-

tion will not reach the listener's ears in phase and as a result will not be magnified in the same proportion. Indeed, the sum total may be less than that given by a single receiver through destructive interference.

Although several types of detectors employing a single receiver for each ear, as in the " 3-Spot," have been developed at the Naval Experimental Station for special purposes such as equipping light-ships, hydroplanes, dirigible balloons, etc., yet the major part of the efforts of this Station have been directed toward the development of the so-called "multi-unit" detector devices.

Except that the "4-Spot" arrangement of receivers has been used throughout in preference to the " 3-Spot " arrangement, these special single-unit types of detectors are very similar to the " 3-Spot " type which has been described. Therefore a detailed description will not be given. The principle and operation of the more effective devices, those employing multiple units, follows:

The so-called "*M-B Tube*" is a rotating listening device employing multiple unit receivers. The principle may be understood by considering Plate X. In Fig. 1 let the numerals 1, 2, 3, and 4 represent four similar acoustic receivers equally spaced in a line and connecting through equal length tubes with the stethoscope leads R and L at the common junction (A). Sound coming from a direction perpendicular to the line of receivers actuates all the receivers simultaneously and the response from all four reaches the ears in phase. Under such conditions the intensity of the sound heard is four times the intensity from a single receiver.

Sound from any other direction, such as represented by arrow 2, does not reach the receivers simultaneously and, as a result, the responses from the various receivers do not arrive at the ears in phase. The intensity of the resulting sound will therefore be less than four times that from a single receiver. The difference will vary for the different components of the sound depending upon the wave-length.

Such an instrument is capable of determining direction by means of the maximum-minimum principle except for an ambiguity of 180 degrees. If, as in Fig. 2, half of the receivers is connected to each ear respectively, then advantage can be taken of both the maximum-minimum and the binaural principles. The sound response from

each receiver of each group reaches its respective ear in phase, thereby giving a maximum intensity for any sound traveling in a direction perpendicular to the line of receivers, as represented by arrow 1'. Moreover, the resultant sound at the two ears will be in phase so the listener will hear the sound binaurally centered. Sounds
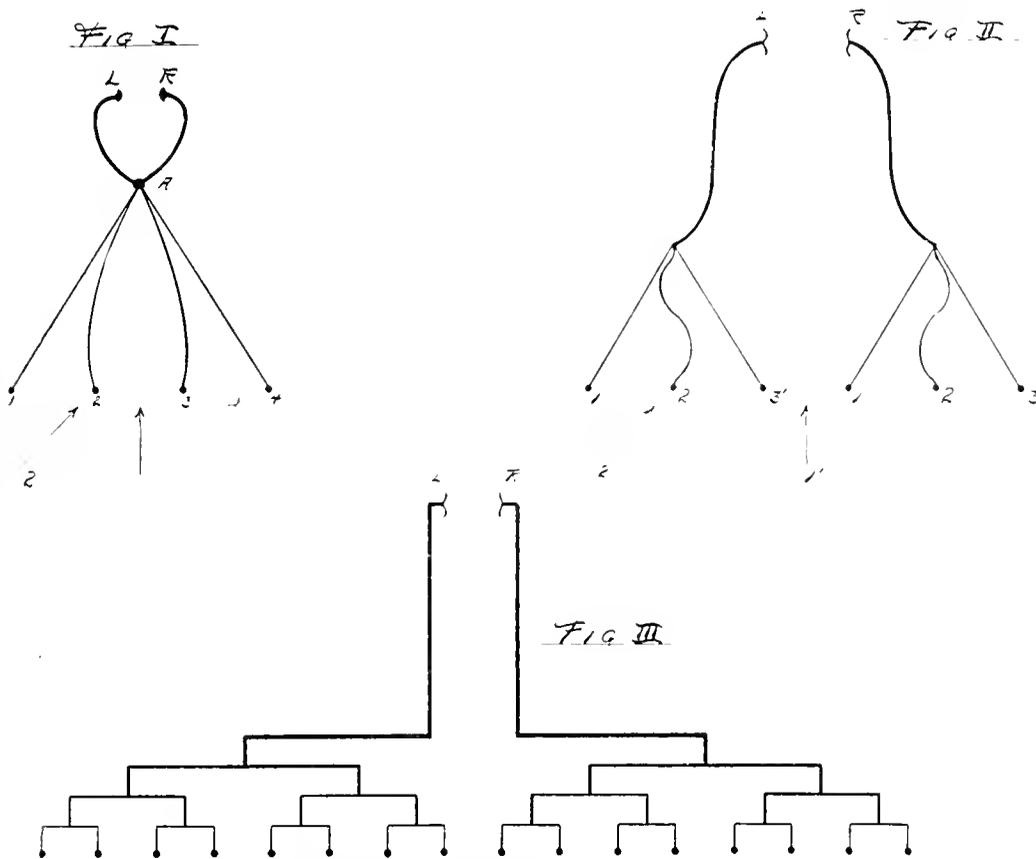
PLATE X.   Principles of M-B tube.

from any other direction, such as represented by arrow 2', will not reach the ears in phase and therefore will be weakened in intensity in both ears. As represented, the composite sound reaching the left ear will arrive in advance of that from the group of receivers connecting with the right ear. This weakened sound will therefore not be binaurally centered but will appear to be located to the left of the listener. Such sounds are often spoken of as being " out of focus."

The intensity of sounds " in focus " is directly proportional to the number of receivers connecting with each ear. The intensity of sounds out of focus depends upon the length of line, the spacing of

the receivers, the wave-length of the sound, and the angle by which it is out of focus.

In practice an eight foot line has been used carrying sixteen receivers, eight connecting with each ear. Fig. 3 gives the scheme by which the receivers are connected. It is to be noticed that the path from each receiver to the ear is the same. Care is also taken to preserve the cross-section of the path. The cross-sectional area of the tube joining each ear is twice that of the branching tube into which it terminates. This branching tube has twice the cross-section of the two branching tubes at its terminals, etc. Sound reflection within the instrument, and hence resonance, is minimized by this means.

Like the C-Tube, the M-B Tube has the disadvantage that it must be lowered and raised when bearings are taken, but it possesses several advantages over the C-Tube. It is most sensitive to sound from a direction at right angles to the tube and is, therefore, relatively insensitive to sounds from other directions. This makes it possible to pick a particular ship out of a mass of disturbing shipping much more readily with the M-B Tube than with the C-Tube. The M-B Tube hears the boat at which it is pointed with much greater intensity than other boats, whereas the C-Tube, or any detector employing a single unit to each ear, hears all boats with the same relative intensity. Furthermore, the M-B Tube is much less disturbed by local water noise than is the C-Tube as a great part of this noise is out of focus. The M-B Tube is only focused on noise in a plane perpendicular to the tube at its central point.

It is obvious that two boats separated by 180 degrees will both be in focus because of the bi-directional properties of the M-B Tube.

The principle of the *M-F Tube* is shown in Plate XI. Suppose (*A*) and (*B*), Fig. 1, represents two receivers spaced a unit distance apart and that sound is proceeding in the direction from (*A*) to (*B*), as represented by the arrow. If the two receivers are joined by a tube there is some point, (*p*), where the sound from the two receivers arrives in phase since the sound wave travels from A to B through the water in less time than it travels from A to B through the air in the tube. This point can readily be shown to be $^{65}/_{100}$ of the distance from A to B. A branch tube leading from point (*p*) will receive the impulses from both receivers in phase.

A line of receivers connected in the manner shown in Fig. 2 is termed an M-F Tube. Only sounds from one definite direction, that shown by the arrow, reach the listener's ear in phase and this results in eliminating to a great extent all local surface noises. Such a line of receivers arranged to rotate in a horizontal plane makes an

Fig. I.

$$\frac{x}{V_{AIR}} = \frac{l}{V_{WATER}} + \frac{l-x}{V_{AIR}}$$

$$2x = l + \frac{V_{AIR}}{V_{WATER}} = l + .23$$

$$x = .615$$

Fig. II.
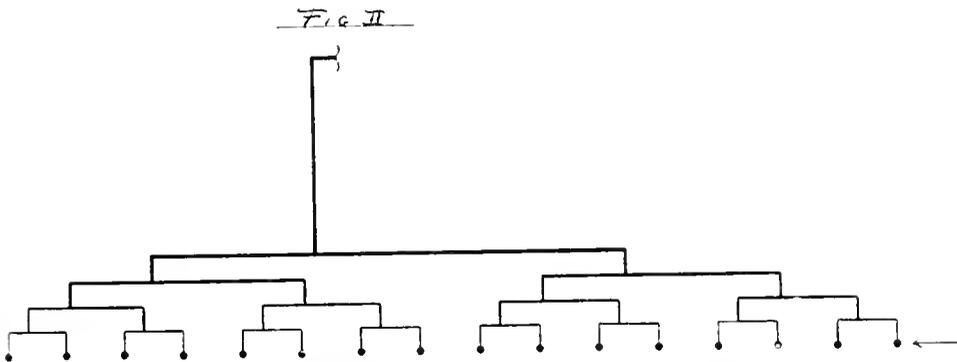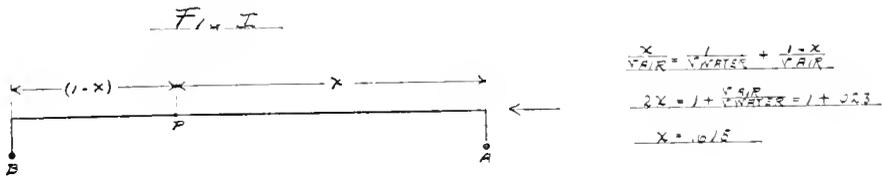
PLATE XI. Principle of M-F tube.

excellent maximum instrument. In practice two such lines are mounted side by side with a horizontal separation of about four feet. By connecting the outlet from each line of receivers to the two ears respectively the binaural principle for determining direction can be utilized. In Plate XI. *a* is shown one type of the double M-F Tube designed for use on submarine chasers.

An instrument of this kind gives a binaural centering of sound at the same time that it is at a maximum, precisely as does the M-B Tube. It is at the same time much freer from water noise than the M-B Tube because it is in focus for sound from only one direction. The M-F Tube has no ambiguity of 180 degrees as has the M-B Tube and the C-Tube. Because of the combination of these desirable properties, the double M-F Tube is the best rotating hydrophone device that we have.

The "M-V Tube" is a listening device employing multiple receivers equally spaced in a line and mounted in a fixed position
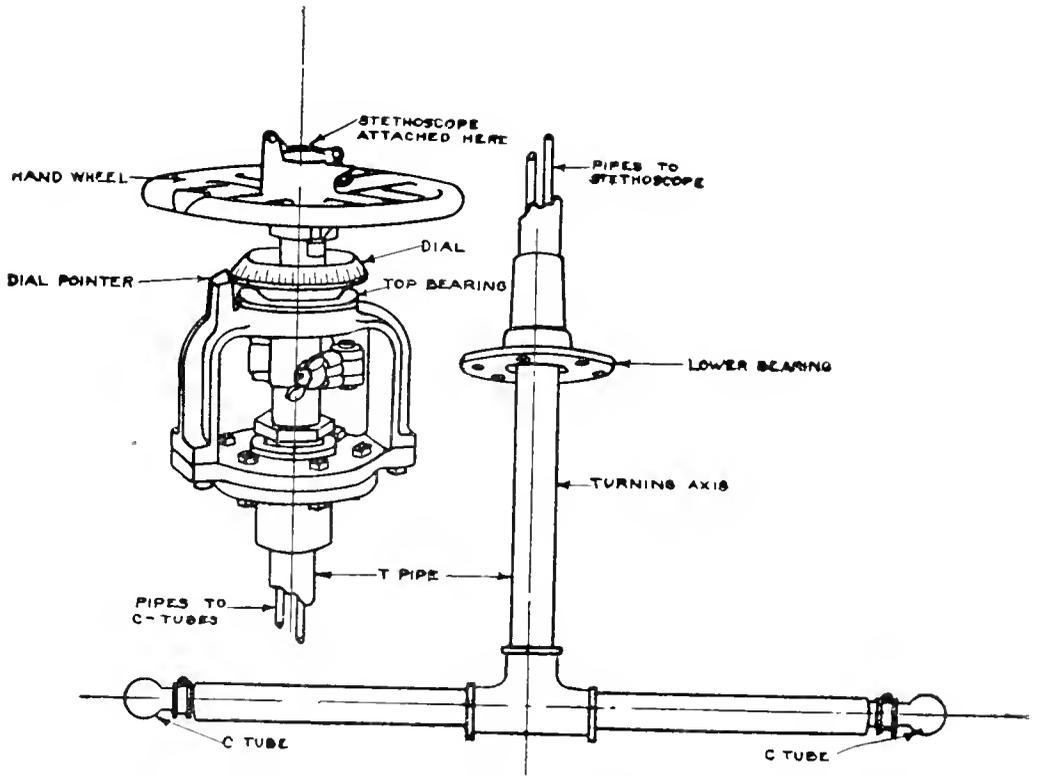
PLATE VIII. *a.*   One form of "C-Tube" developed at the Nahant Station.
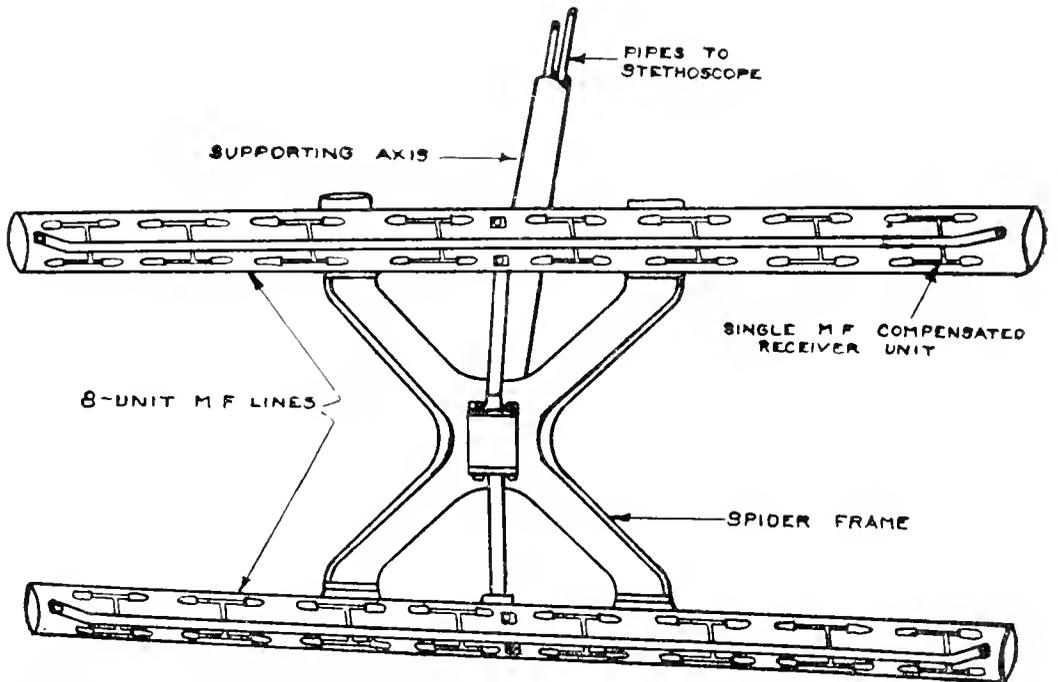
PLATE XI. *a.*   One form of Double M-F Tube.   Portion of casing removed to show receiver units.

within a large tank inside the ship or more usually underneath a protecting blister on the outside of the ship's skin. The line of receivers is in all cases mounted as near parallel to the ship's keel as conditions will permit, one such line being mounted on each side of the ship and directly opposite one another. The receivers in each half of the line are grouped together, each group connecting with one ear respectively, in order that the binaural principle may be employed in determining direction.

Theoretically the focusing effect is intensified by increasing the length of line and the number of receivers, but practically the mechanical difficulties encountered in compensation tends to limit both the length of line and the number of receivers. The principle of operation of a line of twelve receivers is shown in Plate XII.

In Fig. 2 let numerals 1, 2, and 3 represent three receivers equally spaced and connecting to the common junction through the three separate paths a, b, and c respectively. Paths a and c are provided with a trombone arrangement such that their length can be varied at will while path b has a fixed length equal to that of both a and c when the trombone slides are adjusted to have equal paths. The response from the three receivers will reach the junction A in phase for sound travelling in a direction perpendicular to the line of the receivers, that represented by the arrow.

Sound proceeding in a direction as represented by the arrow in Fig. 1 does not actuate the three receivers simultaneously but in the order 1, 2, 3. It is evident that a proper lengthening of the path a and the same shortening of the path c will bring the responses from the three receivers in phase at the junction A. If the sound comes from a direction as indicated in Fig. 3 the variation of the paths a and c must be in the opposite order to bring the responses from the receivers in phase at junction A.

Consider a line of twelve equally spaced receivers divided into four groups of three receivers each, as shown in Fig. 4. Receivers 1 and 3 connect to the junction A through a simple "2-Spot" compensator of the type already described, while receiver 2 is connected to A through a fixed path equal to that from both receivers 1 and 3 when the compensator is so adjusted that their path lengths are equal. The responses from the three receivers can be brought to A

in phase for sound coming from any particular direction by properly adjusting the compensator. Also a similar adjustment of each compensator in the other three groups will bring the response from the three receivers of each group in phase at their respective junctions *B*, *C*, and *D*.

For convenience the four junctions *A*, *B*, *C*, and *D* may be regarded as four separate receivers located at points 2, 5, 8, and 11 respectively. The responses from *A* and *B* can be brought together
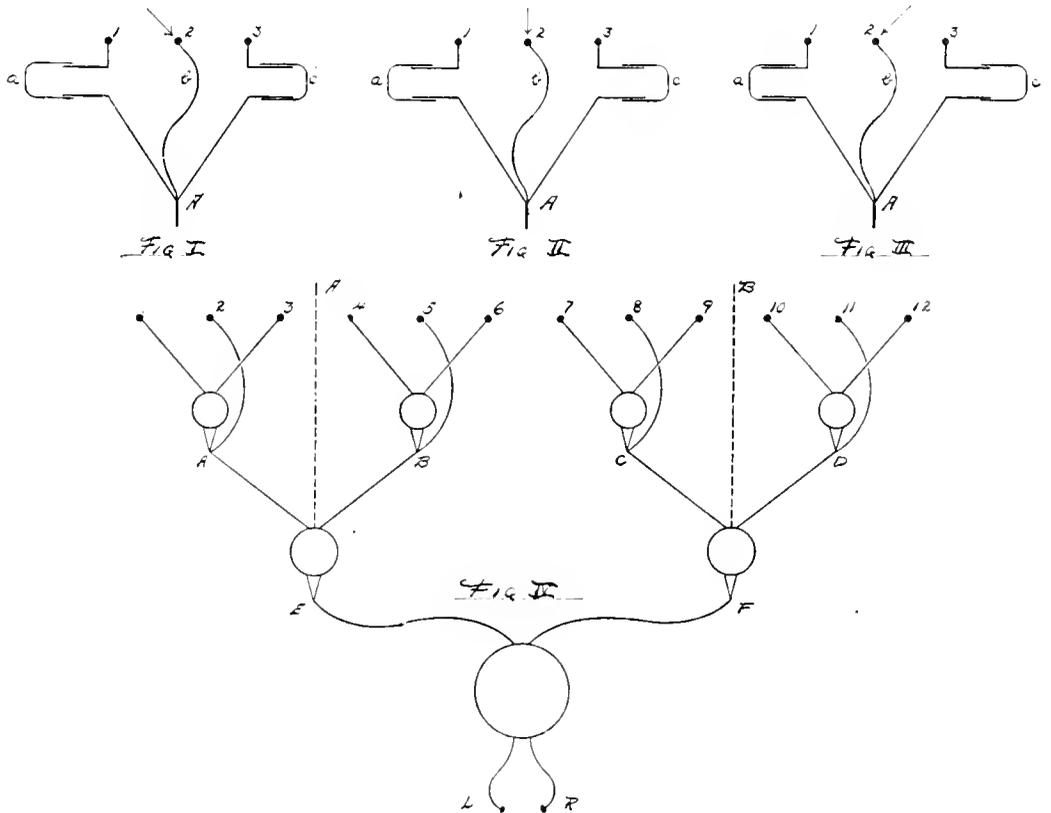
PLATE XII. Principle of M-V tube.

in phase at *E* by means of another "2-Spot" compensator and similarly the responses from *C*, and *D* can be brought in phase at *F*.

Points *E* and *F* may, for convenience, be regarded as two separate receivers located at a point midway between 3 and 4 and between 9 and 10 respectively. These two receivers connect with the ears through another compensator and the stethoscope leads *L* and *R*, and by properly adjusting the compensator the sound can be binaurally centered and the direction of the sound source determined with an ambiguity as to port or starboard. This ambiguity is readily

removed by comparing the intensity of the sound as given by the port and starboard lines since the ship acts as an efficient sound screen.

From the description it is obvious that the complete compensation of a line of twelve receivers is accomplished in three separate stages. First, the 4 groups of the receivers are compensated by means of four similar compensators. The maximum compensation to be effected in this stage is, in terms of water-path, equal to the distance between two adjacent receivers. Second, these four groups are compensated in pairs by two similar compensators. The maximum compensation to be effected in this stage is, in terms of water-path, equal to one and a half times the distance between two adjacent receivers. Third, these two groups are brought into phase to give a binaural centering. The maximum compensation to be effected in this last stage of compensation is, in terms of water-path, equal to three times the distance between two adjacent receivers.

Since the amount of compensation effected in the three separate stages is in the ratio of $2:3:6$, it follows that all the compensators will require the same angular setting if the average radius of the grooves for the compensators of the three stages has this same ratio respectively. Under such conditions the seven compensators can be geared together so that a rotation of the binaural compensator by the operator will produce the same angular motion in all, and when a sound is binaurally centered all the compensators are so adjusted that the intensity of the sound is a maximum. The compensation, which as described requires seven separate compensators, is all accomplished by a single compensator known as the " Type H," the principle of which is shown in Plate XIII.

The four groups of three receivers each connect through the bottom plate of the compensator to the points represented by numerals 1 $\cdots$ 12. The path from receiver 1 includes the groove from 1 through s and back to A in the movable upper plate of the compensator while the path from receiver 3 includes the groove 3–T–A. Receiver (2) connects directly to point 2 on the compensator plate through a path length equal to that of receivers 1 and 3 when each groove path is the same. The other three groups of three receivers are similarly connected to the grooves of the other three quadrants.

Sound from receivers 1, 2, and 3 can be brought into phase at A by rotating the groove to a proper position with respect to the fixed openings 1, 2, and 3. At the same time the three receivers of each of the other three groups will be brought into phase at the points B, C, and D respectively.
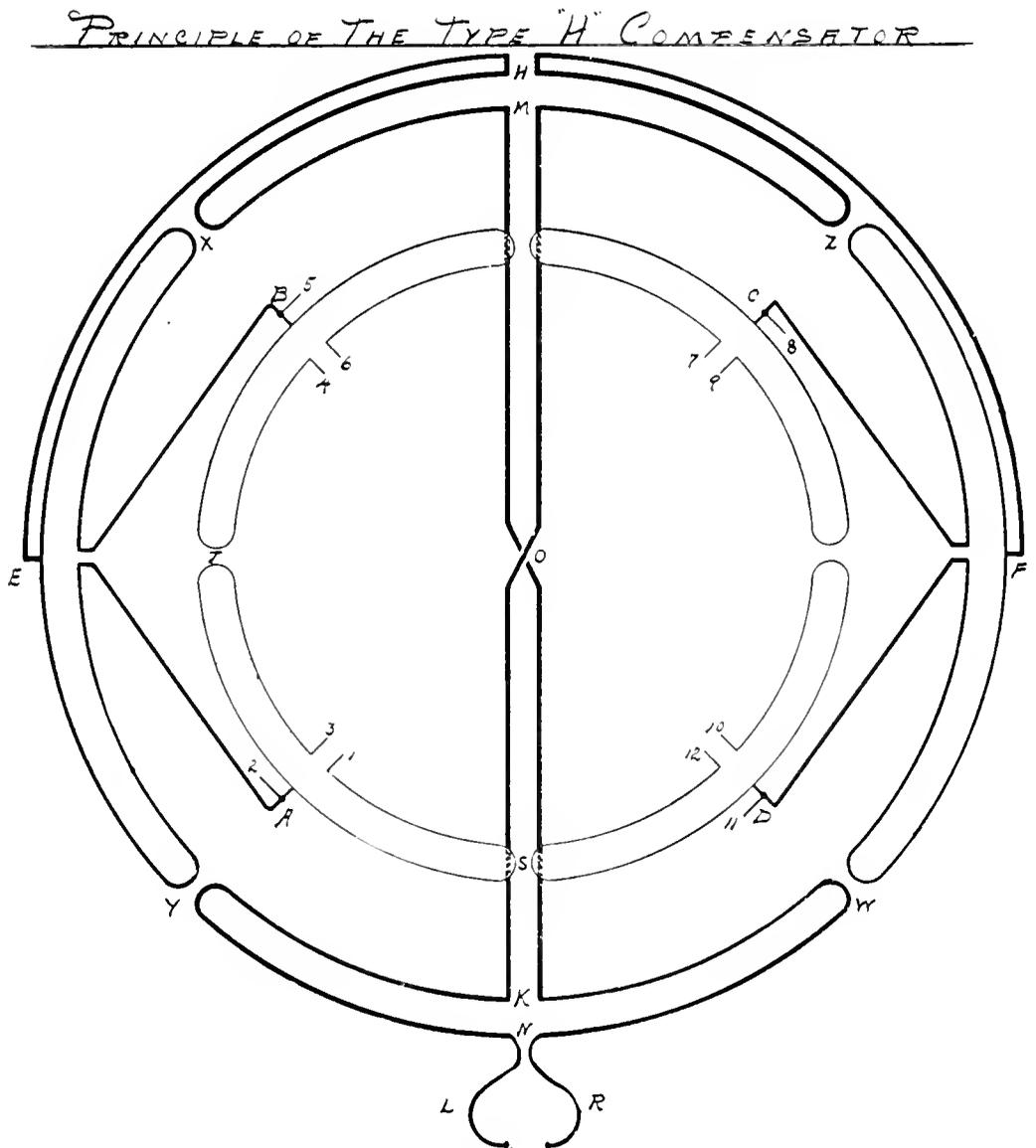
PLATE XIII. Principle of Type-H compensator.

Sound from points A and B are conveyed through two fixed grooves of equal length in the lower plate to another compensating groove in the movable plate, the sound from B passing around the end marked X and that from A passing the end marked Y. Both sounds unite in a single path at E. The sounds from C and D are similarly united in a single path at F.

The two sets of grooves are so made that their average radius has the ratio 2 : 3 in order that the compensation effected in the second stage may be one and a half that effected in the first stage which has been shown to be necessary. It remains to be shown that the
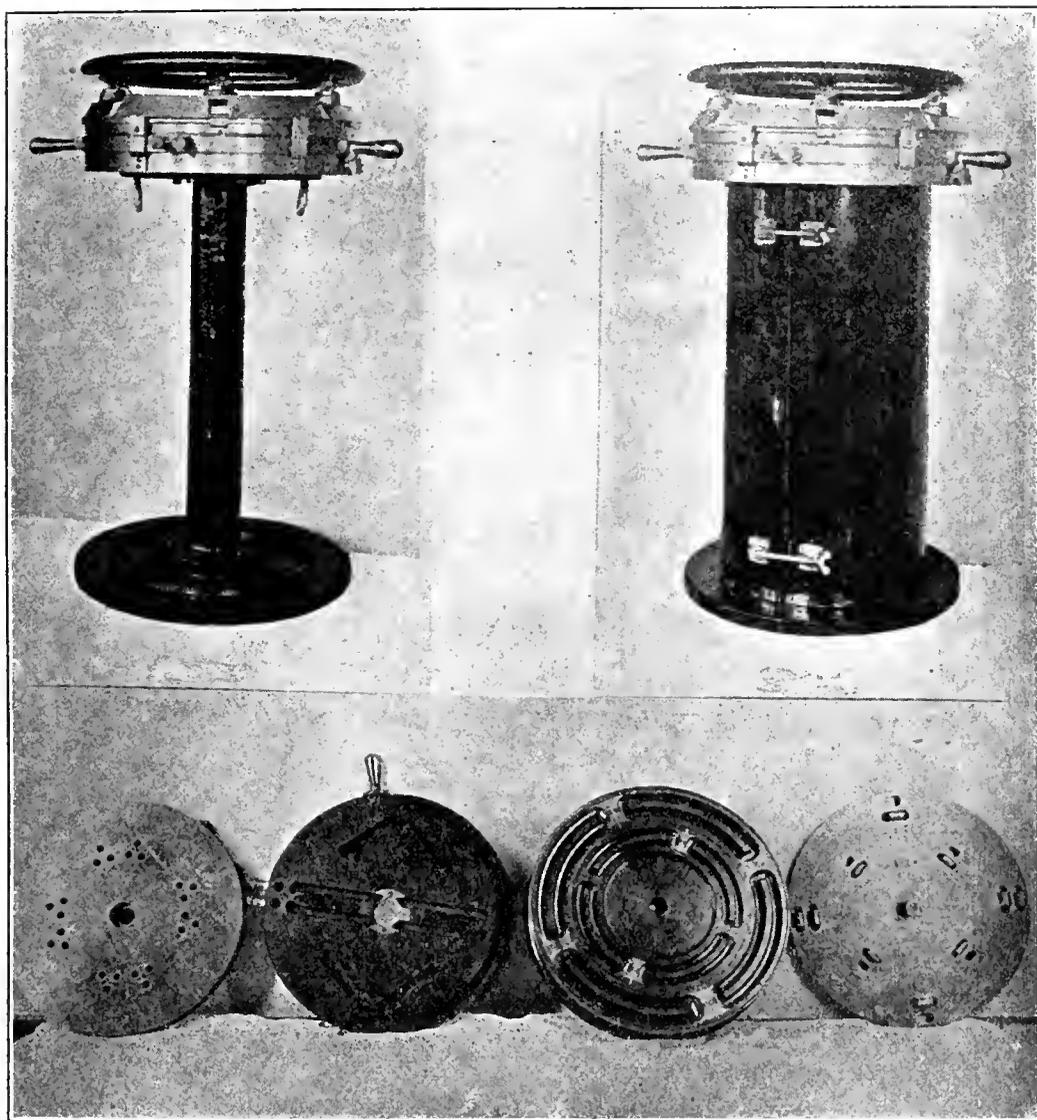
PLATE XIII. *a.* The Type-H compensator, showing structure of grooved plates for compensating twelve acoustical units.

sound from the two points E and F suffers during the third or binaural stage three times the compensation effected in the first stage whenever the top plate is turned.

The course of the sound from E to the listener's ear is: E to H through fixed path in lower plate; H–X–M through compensating groove in upper plate; M–O–K through fixed groove in lower plate;

K–W–N through compensator groove in upper plate; N–R through stethoscope lead to right ear. The sound from F traverses a similar course, viz.: F–H–Z–M–O–K–Y–N–L ending at the left ear. It is readily seen that the compensation effected between E and R and between F and L when the upper plate of the compensator is rotated
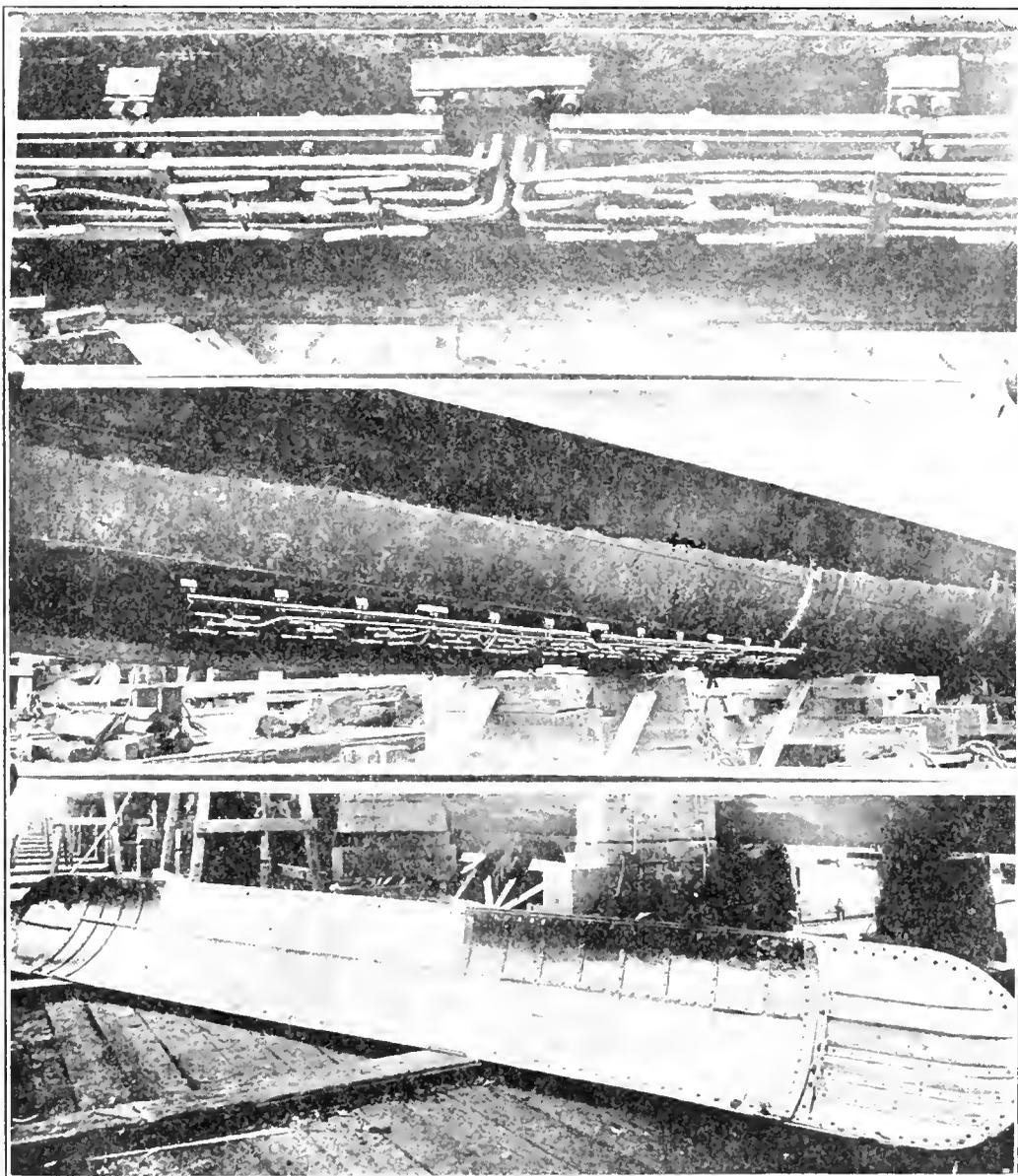
PLATE XIII. *b.* The acoustical M-V installation and protective blister.

is double that effected between E and (B or A) since in the former case two grooves are connected in series. Thus all the requirements for complete compensation of twelve equally spaced receivers mounted in a line are met.

The dimension of the grooves through the compensator are such as to preserve uniformity of cross-section. A third bottom plate is provided and so arranged that by rotating the second plate, which carries the fixed grooves and stethoscope leads, upon this through a small angle either the port or starboard line of receivers can be connected through the compensator.

The three figures in Plate XIII. *a* give the appearance and construction of the Type H Compensator in detail. Plate XIII. *b* shows the manner of mounting the line of receivers beneath a streamlined protecting blister on the outside of the hull.

The M-V Tube determines direction by means of variable compensation instead of by rotating the line of receivers and therefore is free from the weaknesses inherent in the M-B Tube and the double M-F Tube. Its focusing effect is superior to either of these devices because of the greater length of its line of receivers. It is more rapid and easy to operate since it only requires the rotation of the compensator plate to center a sound binaurally. And, finally, it can be operated while the boat is moving. The M-V Tube is without doubt the best " on-board " listening device thus far developed. Some idea of its ability to locate a submarine can be gained from Plate XIV.

The full line curves represent the true course of a submerged submarine. The coördinates of the curves have time for abscissæ and angular bearing with respect to the listening boat as ordinates. The round circles represent bearings as determined on an early form of M-V Tube. The speed of the listening boat, a destroyer, is given by the broken line curve at the top of the sheet and the distance in yards of the submarine is marked at various points along the curve.

The M-V Tube in its later forms makes use of twenty units instead of twelve. These installations are capable of giving better results than those recorded in Plate XIV. The possibilities of the M-V Tube will not have been reached until a compensator is devised which will take care of a line of receivers spaced about fifteen inches apart and extending the entire length of the boat upon which it is installed. Experimental results however seem to suggest that the advantage to be gained by extending the line of receivers much beyond forty or fifty feet is scarcely worth striving for.
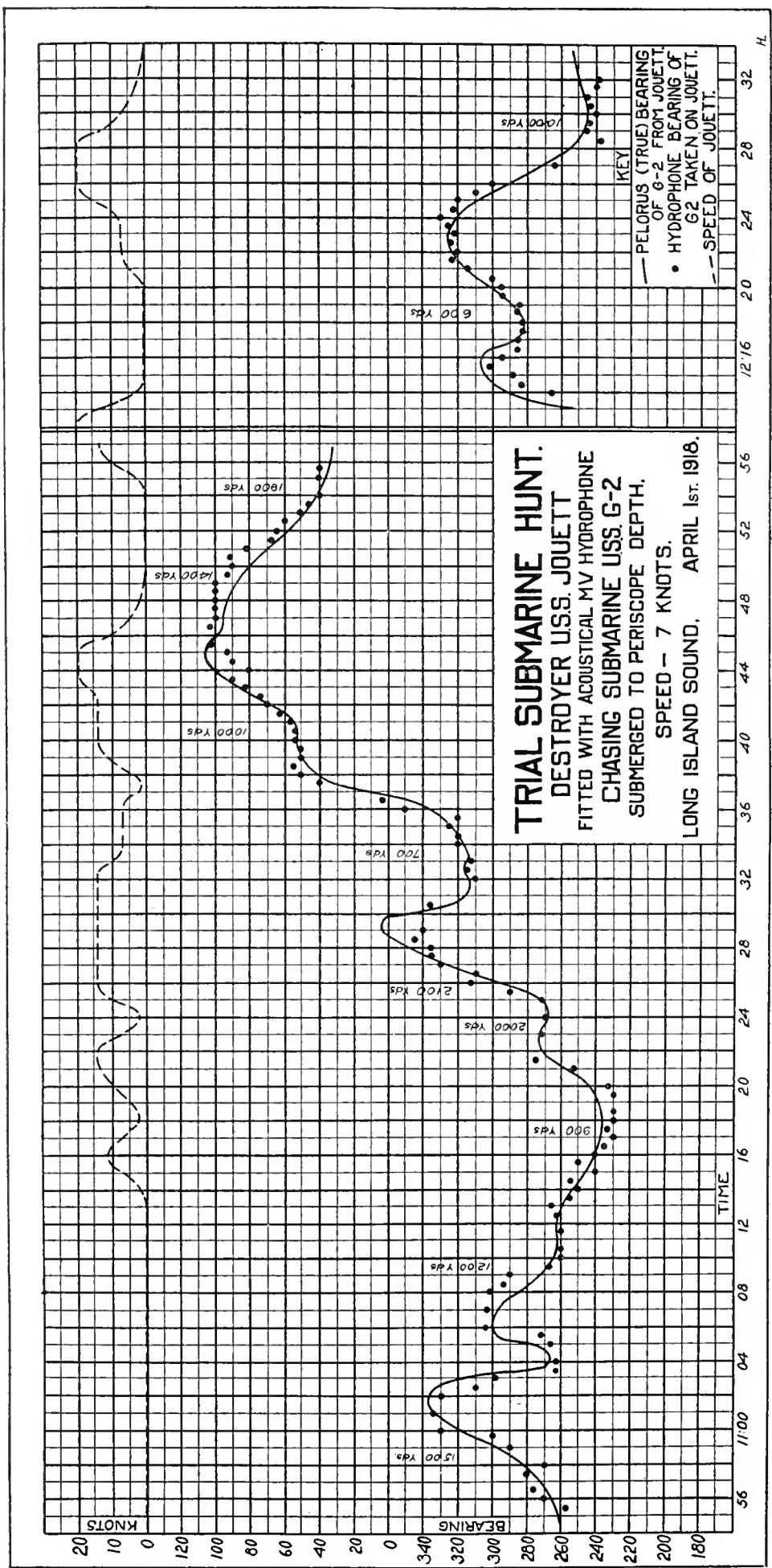
PLATE XIV. Typical curve taken on submarine hunt with acoustical M-V equipment.

The statement that no increase in range is to be gained by increasing the sensitiveness of the receivers beyond a certain point obviously does not apply when the receivers are used in multiple since the local and other disturbing noises are not intensified in the same proportion as the sound upon which the receivers are focused. More sensitive receivers can be effectively employed in multiple unit devices than in single unit devices such as the " 3-spot " and " 4-spot."

The sensitiveness of the acoustical receivers is not as high as can

A

B
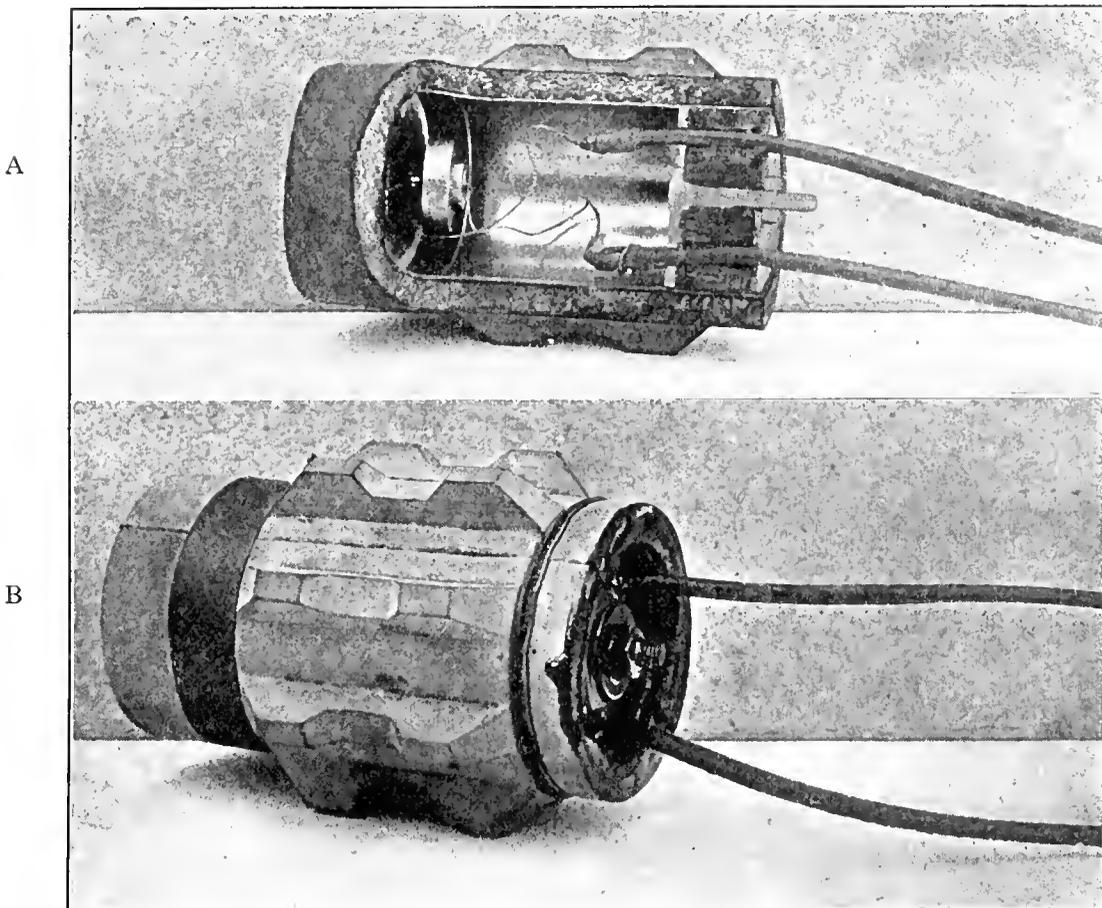
PLATE XV. The microphone housing developed at the U. S. Naval Experimental Station. *A,* Section through interior showing microphone. *B,* Complete receiver unit, about ½ natural size.

be advantageously used in multiple unit devices. This fact, together with the need for a long range listening device led to the development of several types of electrical listening devices employing multiple receivers. A description of these devices follows:

The U-3 Tube is a submarine sound-detecting device which can

be towed astern from a moving boat at any desired distance. In principle it is an electrical copy of the M-V Tube above described. Two lines of twelve equally spaced microphone receivers are connected through a multiple unit electrical compensator to a head set
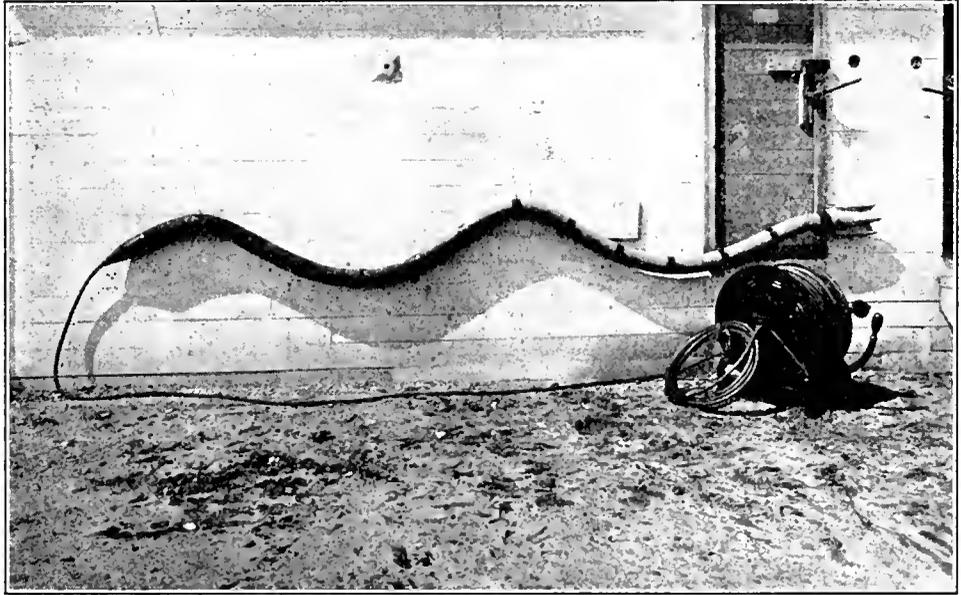
PLATE XVI. The twelve-spot microphone eel and cable reel.

of two carefully matched telephone receivers. The microphone receiver developed for these lines is fully as sensitive as the "rat" and gives a more faithful reproduction of phase, a requirement for receivers used in multiple. The construction of this receiver is shown in Plate XV.

Each line of twelve receivers is housed in a flexible gum rubber tube which is stopped at either end by properly streamlined forms. A line of receivers so housed is called an eel. Electrical connection between the receivers and compensator is made through a 14-conductor cable which can be payed out or in from a specially designed reel without breaking the electrical circuits. Plate XVI. shows the eel with its cable and reel. Plate XVII. shows the Type AE–2 electrical compensator, used to compensate the receivers in the eel.

The U-3 Tube consists of two similar eels towed abreast, each by its own separate cable. The eels, because of their flexibility, do not skid when eddies or cross currents are encountered and thus keep their relative position without the use of a spreader. Their

horizontal distance remains the same as that between their respective cables at the boat's stern with but slight variation.

Every unit in the construction of an eel (head, tail, housing tube, and each of the twelve receivers) is carefully designed to have neutral buoyancy in sea water when the eel is filled with fresh water. This assures that the line of receivers will lie in a horizontal plane
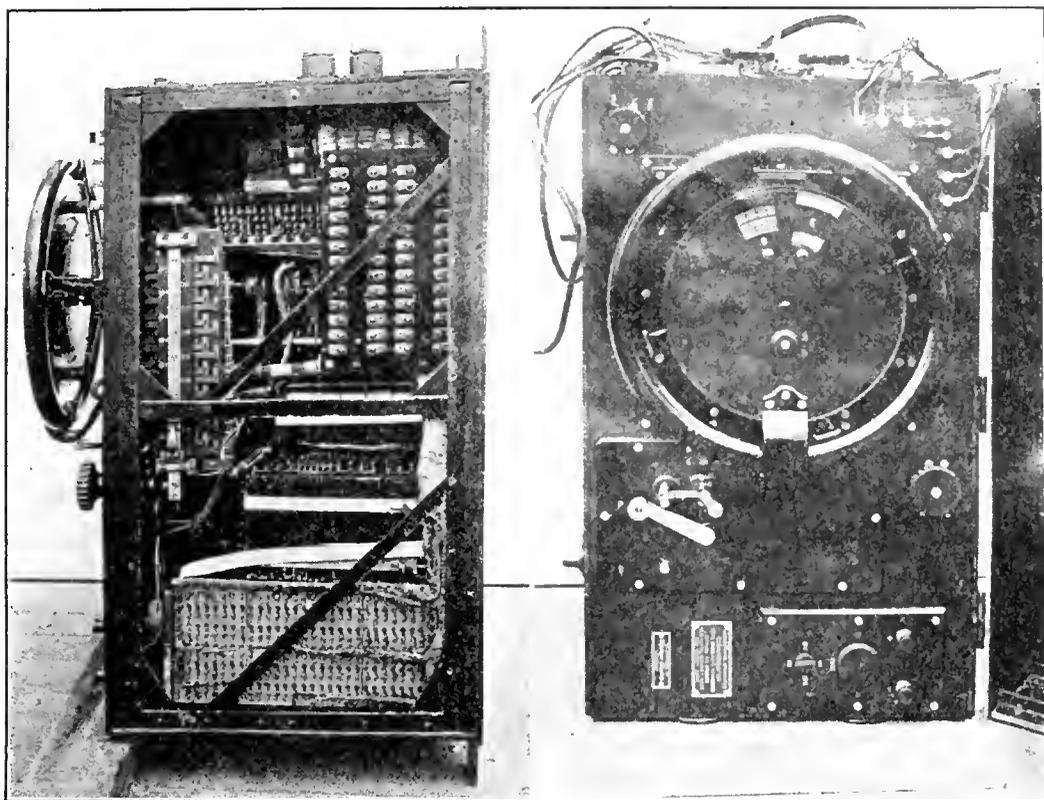
PLATE XVII.   The AE-2 electric compensator designed to accommodate two sets of 12-spot microphone lines.

so long as there is any appreciable relative motion between the eel and the water.   The depth at which the eels trail depends upon the length of cable and the speed of the boat.   In practice this depth is kept within 100 feet.

The electrical impulses from the microphone receivers, produced by sound from any particular direction, are brought into phase at the two telephone receivers by means of a rotating switch arrangement which introduces the proper amount of loaded line into the separate microphone circuits.   The 6 microphones in the forward half of the receiver line attach to one telephone and the rear 6 connect with the other.   The construction of the compensator is such that the same

setting which brings a sound into focus causes it to appear binaurally centered and the rotating switch carries a scale and pointer indicating the bearing (ambiguous of course as to port or starboard).

The ambiguity cannot be removed by comparing the intensity of the sound as given by each line of receivers (the method employed for an "on-board" installation) since there is no sound screen between the two lines. It therefore becomes necessary to make a second compensator setting on two groups of receivers which have their line of centers in a different direction. This can be done by using six receivers in each eel. The direction will then be the common angle of the two compensator settings as has been shown.

A switching arrangement is provided whereby the twelve receivers in the port eel, or the starboard eel, or the six forward receivers of both eels, or the six rear receivers of both eels can be connected through the compensator to the two telephones. Furthermore the compensator is so designed that the last stage of compensation, the binaural stage, can be uncoupled and varied independently of the other two stages which may be termed the maximum part of the compensation. Whenever compensation is effected across the two eels, i. e., between the head groups or tail groups of receivers, it will be seen that the binaural part of the compensation must be made independently of the maximum part.

Suppose a binaural setting has been made on a sound when the 12 receivers of, say the starboard eel, are connected through the compensator. The maximum part of the compensation is properly adjusted to bring the impulses from each group of 6 receivers—the head group and the tail group—into phase. The resultant of each group is brought into phase by the binaural part of the compensation and the compensator is so designed that the same angular rotation is required for both stages. Now if the six receivers in the head of the port eel are substituted for the rear six in the starboard eel and in the same order, it is evident that the compensator adjustment for maximum still holds for the reason that this is determined by the angle between the line of the receivers and the sound. This angle remains the same in both cases since the two eels are parallel. But the phase difference between the resultant of the two groups will in

general be different in this second case so that the binaural part of the compensation will need to be changed to give a binaural center.

The switching arrangement in the compensator is designed so that whenever the receivers are connected in for cross-compensation a clutch which connects the maximum and binaural parts of the compensation is automatically released leaving the binaural part free to turn while the maximum part remains fixed. This clutch automatically falls back into position whenever the port or starboard line of receivers is switched to the compensator.

The direction of a sound source is then determined on the U-3 Tube as follows: Connect the receivers in either eel to the compensator and make a binaural setting, then connect either the head or tail groups to the compensator and make a second binaural setting. The common angle on the two double scales is the direction.

The compensator is provided with two electrical filters either of which can be connected in series with the telephones at will. These filters allow all sounds above a certain definite frequency to readily pass but eliminate almost entirely the lower frequencies. One filter limits the passage to frequencies above 450 and the other to those above 900. Very often disturbing noises can be largely eliminated by using one filter or the other without weakening the comparatively high pitched sound from a submarine.

The U-3 Tube is one of the best listening devices that has thus far been devised. It can readily be installed on any boat without docking, is durable and easily repaired and rapid in manipulation. It can be operated at fairly high speeds because its streamlining is such that it produces very little water noise itself while it can be towed far enough astern to reduce the water noise and other noises on the listening boat to a minimum. It has the longest range of any of the various types of submarine detectors due to the fact that it employs highly sensitive receivers in multiple combination, operates at sufficient depth to largely eliminate surface noises, and at a sufficient distance from the listening boat to largely eliminate local noises, and due to its focusing qualities desirable sounds are intensified while other sounds are relatively weakened.

The use of multiple unit electrical lines is not limited to towing devices. As an " on-board " installation the electrical MV has cer-

tain advantages over the acoustical. It is more sensitive and there-
fore capable of giving greater range. It can be housed within a
water-tight blister in such a way that the line of receivers can be
withdrawn through a hand-hole opening in the skin of the ship and
repaired or replaced without docking the boat. The installation as
a whole has proved more durable than the acoustical lines. If a re-
ceiver becomes defective it can be cut out and the line can still be
used, whereas a leak in the acoustical line allows the installation to
fill with water and thus become useless. Finally, the compensator
can be placed on or near the bridge whereas the listening station for
an acoustical MV must be placed near the inlets through the ship's
skin. This location must necessarily be near the keel of the boat and
as a result considerable distance from the bridge.

On the other hand, the quality of the sound and the selectivity
given by the acoustical MV is superior to that given by any electrical
MV thus far produced because of the fact that the acoustical re-
ceivers are better matched than are the microphone receivers. How-
ever, improvements in the construction and matching of the micro-
phonic receivers are continually being made and there is all reason
for believing that the electrical MV will soon be made to compare
very favorably with the acoustical MV as regards quality of sound
and selectivity.

The perfection of the electrical MV has made possible the use of
two or more lines of receivers with the same compensator. The type
AE-2 electrical compensator developed for use with the multiple
microphone eels is provided with a multiple unit switch whereby it
can be connected with either the two eels, as described, or to two
" on-board " lines enclosed in blisters. This combination is very
favorable for searching submarines for the reason that the eels can
be used for picking up faint or distant sounds thereby directing the
listening boat to a point where the submarine can be heard and fol-
lowed by means of the " on-board " lines. Moreover, the distance of
the submarine can be judged with some accuracy by determining its
bearing on both the eels and the " on-board " lines. The distance
between the eels and the blisters being known the range of the sub-
marine is readily determined by triangulation. While this method
does not determine range with sufficient accuracy for bombing pur-

poses it is sufficiently accurate to be helpful in making an approach.

Plate XVIII. shows the range chart used in connection with this type of installation. Range curves are plotted in terms of the angular bearings on the two installations. As an example, suppose the
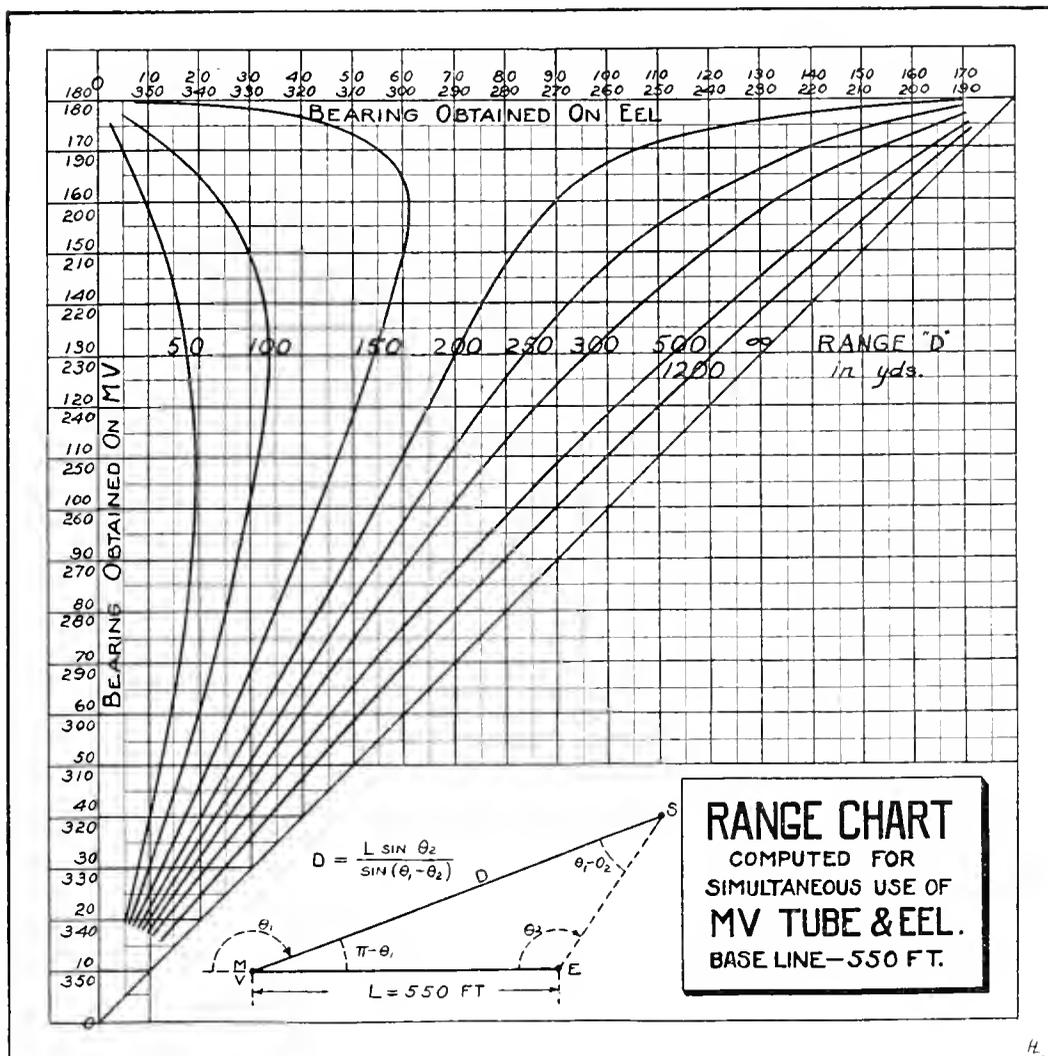
PLATE XVIII. Range chart—computed for two detectors with base line of 550 feet.

bearing of the submarine as given by the eels and the " on-board " lines are 43 degrees and 120 degrees respectively. The range of the submarine would be 125 yards.

The development of the principle of electrical compensation has made possible the use of long lines containing many receivers so it would seem that the limiting possibilities of the submarine sound detector have by no means been reached. In fact the usefulness of

these devices in peace times as well as in war times is but imperfectly realized, but it is a safe prediction that the future will find them a distinct safeguard to navigation.

The Value of the Submarine Sound Detector as an Instrument of Warfare is not to be measured by the number of " U-boats " that by its aid have been located and damaged or sunk but rather by the resulting curtailment of their radius of operation and the effect on the morale of their officers and crews. The U-boat in operation was never safe after the perfection of the submarine detector. When traveling at sufficient speed to cover any distance it could be heard and accurately located at a range of several miles. The same was true whenever it lay on the surface charging its batteries. It could, in some localities, lie at rest on the bottom or if the depth prevented this it could run very slowly, about one and a fourth knots, at a depth of from 100 to 200 feet and thus be reasonably free from detection but under such conditions it was comparatively harmless.

Submarine sound detectors promise to become a distinct aid to navigation during conditions of low visibility. Its aid is two-fold: first, approaching vessels can usually be heard and located in time to avoid collision and second, harbor entrances can be safely made by taking bearings on properly placed submarine signals.

The U. S. S. destroyer *Parker* while maneuvering in the North Sea in a dense fog reported that she avoided two collisions in one day by locating an approaching boat with her listening gear.

Some idea of the aid which can be given in entering a harbor is shown by the results of recent experiments. By means of an electrical MV-Tube on one of our transports, the writer recently located the Nantucket Light-ship within two degrees at a distance of 37 nautical miles by picking up its submarine bell signal, and this was accomplished while the transport was steaming at 15 knots. Had the transport slowed down to ⅓ speed the bell could without doubt have been heard at a range of over 50 miles. While entering New York Harbor from one to three bell signals could be heard and accurately located at any time and as a result the vessel could have safely entered harbor in a dense fog.

It would seem that navigation during conditions of low visibility can be made perfectly safe if each boat is equipped with a good sub-

marine sound detector and a submarine signal device such that its signals can be distinctly heard at a distance of at least five miles. During fog each boat should periodically signal by code its course and possibly its speed. By picking up such signals on its listening device any boat can avoid collision since it will know the bearing, course, and speed of all ships within a radius of five miles.

Such an arrangement should not only eliminate all possibility of collisions *but should enable our whole Merchant Marine to keep moving at practically full speed at all times*, thereby placing it in a better condition for competing with the Merchant Marines of other nations than it otherwise would be.

U. S. Naval Experimental Station,
New London, Conn.
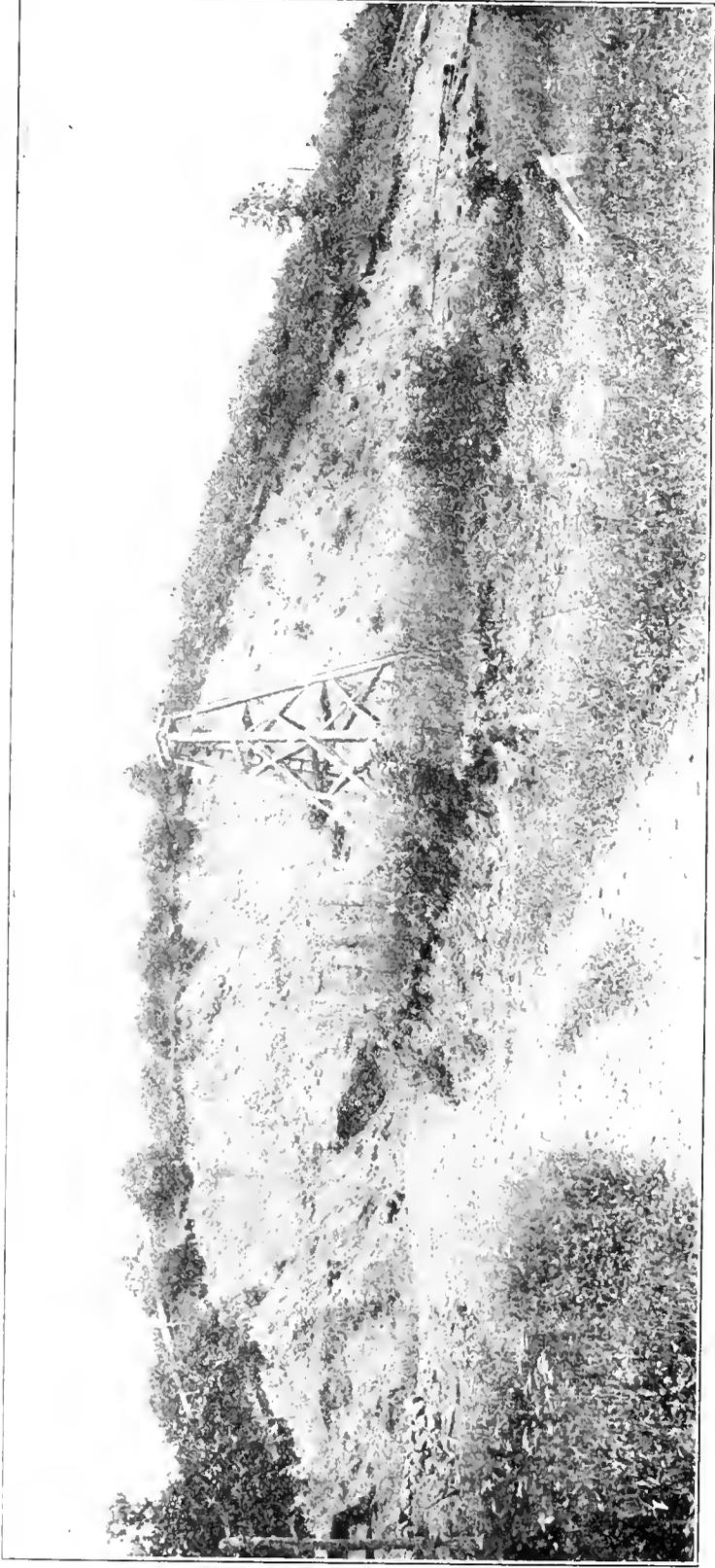
SOUTHERN FACE, *Clarendon Gravels*. INDIAN HOLLOW.

THE DEEP KANSAN PONDINGS IN PENNSYLVANIA AND THE DEPOSITS THEREIN.

PART ONE.

By EDWARD H. WILLIAMS, Jr.

(Read November 5, 1919.)

INTRODUCTION.

As the name " Kansan " is given to the drift in Pennsylvania, south of the moraine of Lewis & Wright, along the Allegheny River, and as it extends across the Delaware River from New Jersey, the intermediate drift in Pennsylvania south of the same will be so called, though it differs almost entirely in petrographic characteristics; as drift everywhere tends to conform to the outcrops on which it lies, and only in moraine or overwash accumulations is there a general and indiscriminate mixture.

It is proposed to-night to examine the character and the origin of the high-level gravels along Allegheny River, concerning which there is a difference of opinion. Other gravels will be used as illustrative material.

Professor G. F. Wright expressed the opinion in 1894[1] that some of the Allegheny gravels were remnants of a complete valley filling, since excavated; but he abandoned this theory later. In 1902 F. Leverett[2] expressed Wright's former opinion. Beginning in the Lehigh Valley, in 1892, E. H. Williams, Jr.,[3] found that the sculpturing of the Kansan outwashes antedated the deposition of the universal capping of iceberg silty clay. This is also the case in the Susquehanna and Allegheny valleys and is applicable to all foreset-bedded glacial outwashes deposited in deep pondings.

Pondings are of two kinds: those against a watershed, with gradually rising surface until a discharge over a col occurs and, if trenching occurs, with gradually diminishing depth: those against persistent or ephemeral ice-dams, with the depth varying with height of the dam. The former class is characterized by a permanence

which produces beach-lines—both filled and undercut—of good definition, high terraces with long and flat tops, and all the signs of long flooding: the latter will rarely persist at an exact level. We shall come upon good examples in this discussion, and when ice-dams occur in a valley like those of the Juniata or of the Allegheny, where there is a fall of the regional surface commensurate with that of the floodplain of the stream, it is evident that the height of the ice-dams would be similarly influenced, and the sporadic bars and terraces formed in the pondings would have a proportional fall in elevation, and of so marked a character that it would simulate the slope of a high gradation plain.

The illustrative material to be examined is found in the Hudson, Lehigh and Juniata valleys, whose streams were never reversed, and whose pondings were against ice-dams: in the Bald Eagle, and in an inconsequential part of the West Branch of Susquehanna River, between Williamsport and Lock Haven, both of which were temporarily·reversed, and whose ponding was between the glacier and a col.

The Allegheny is a patchwork stream. It flows through 4 valleys in reverse, and through 4 trenched cols. There were many pondings with surfaces above 2,100 in the Pennsylvania Highlands; above 1,600; above 1,500; above 1,430, and above 1,200, as we proceed from those highlands to the mouth of Clarion River, where the crests of the region are 1,000 feet lower. The terraces, bars, sporadic areas of gravel of Kansan age partake of the elevation of the ponding, and fall in elevation, as will be seen below.

It is generally acknowledged that there was no sinking of the Kansan border in Pennsylvania during glacial times, and that the isobase of 200 feet crosses the Hudson Valley near Storm King Mountain. We can therefore use the Government and State Topographic Quadrangles to measure relative elevations along that border, and, with proper corrections, elsewhere, during the period treated in this paper. The most of the illustrations which follow have been published before. The photographs were taken by the writer between September, 1892, and August, 1897. It remains to acknowledge his great indebtedness to the late Dr. Joseph Barrell who, as an assistant traversed the entire Kansan Border between the

Delaware and Allegheny rivers. Of the character of his work no encomium is necessary.

Storm King Mountain Ponding.

The Cambro-Ordovician rock floor of the Champlain-Hudson trough varies slightly on either side of the meridian until it approaches Kingston, N. Y., where it forks. The right-hand fork turns westward along a deflection of 20 degrees into the Cambro-Ordovician trough of the Rondout-Wallkill Valley, which is separated from a short valley in the same measures, leading to Delaware River, by a low saddle at 514 feet. Across this stream the Great Valley of Pennsylvania extends, in the same measures, to Maryland, with the highest point of its trough slightly below 500 feet. The left branch turns, at the same angle, eastward into a pocket through which Hudson River flows. The high eastern wall of this valley leaves its average of 16 miles from the stream and approaches it until, at Storm King Mountain, it rises 1,200 feet immediately from the stream edge. Marlboro Mountain forms an equally high wall on the west bank. The average valley width of 16 miles between the 500-foot contours, and of 32 miles between those of 1,000 feet, is constricted between these mountains, and at West Point is about ⅗ of a mile wide at the lower, and 2 miles at the upper elevation. Similar widths at these levels along the Rondout-Wallkill Valley are from 2 to 6 for the lower, and 16 miles for the upper one. At the time of the depression of 200 feet, indicated by the above isobase, the above saddle still rose 314 feet above the then ocean level, and prevented a flow of water towards Delaware River, if the Storm King-West Point pocket were open.

Going north from the pocket we come suddenly, at Kingston, upon thick clean, horizontally-bedded brick-clay carrying infrequent good-sized boulders. Still further to the north the clay grows thin and sandy, with gradual change to foreset-bedded gravel dipping down stream, and in sporadic patches where sheltered from the current. The clay and boulders indicate a current of 2 inches, or less, per second; a depth of water sufficient to float icebergs so high above the deposit of clay as not to disturb its quiet and even deposition; a

stagnation in the pocket, and a high ice-dam as its cause. The gravels are found along the Rondout-Wallkill Valley, and indicate a current of 30 inches per second passing thence from the Hudson, and a depth of water—314 to 514 feet—sufficient to pass over its saddle.

Both clay and gravel are sorts of a glacial outwash. The cleanness of the former indicates a recession of the glacial front to the north sufficient to permit the separation of the sand and gravel sorts from the clay as soon as a slackening of the torrential current occurred. The volume of the torrent can be inferred from the fact that the Hudson Valley drained that part of the St. Lawrence basin which passed through Lake Champlain—all from the glacier and the region between the Green Mountain-Taconic range on the east and the Delaware-Susquehanna watershed on the west, and all from Central New York that did not escape south or west. Such a flood would clear away at once whatever deposits in the Hudson Valley were within the area of scour, as soon as the ice-dam in the pocket became weak.

This episode is an archetype of our periodic freshets, with their high water, their thin washes of slimes and of light trash, and their rapid subsidence. Nobody associates the distance between the high levels reached by the slimes, and the midsummer low water, to which they run continuously, as indicating the depth of excavation in a completely slime-filled valley. Nor do we so theorize about sporadic gravels dropped in deep pondings, such as will now be considered.

Delaware Narrows Ponding.

A similar ice-dam was formed south of Easton, Penna., in the Delaware Narrows, of bergs from the Hudson, and from the glacial lobe which crossed the former river north of Pocono Mountain. It ponded the Lehigh Valley up to 500 feet[3] during the wasting of the Hudson-Delaware-Schuylkill lobe there. As evidence of Arctic intrusion we find *Sedum rhodiola* growing on the side of the narrows where the sun never intrudes. This and Quoddy Head, Maine, are the two habitats of this plant in the United States.

The deposits in this ponding are sporadic. The most prominent

are long ridges of foreset-bedded gravels with infrequent cobbles and boulders, which extend towards the Delaware from the low hills or the projecting shoulders of South Mountain, which formed long areas of diminishing slackness. The bars thus diminish both in height and breadth as they near their ends. The lodging of bergs nearby made changes in the strength of the scour, and we find surfaces of erosion with unconformable beds on either side. This is especially the case at the end of the period when fine gravel was deposited, and the *Packer Clay* with its boulders and iceberg trash followed as a capping. Some of these bergs carried masses of rock weighing four and one half tons, and a heap of such masses were found on top of an eddy hill in what was South Bethlehem.

This clay capping is sandy and but 2 feet thick near lines of current of 5 inches per second; but is 30 feet thick and sand-poor in areas of still water. It lies unconformably over the ends of some of these long bars, and proves that their sculpturing preceded its deposition, and that they were never part of a complete valley filling since excavated. This latter was the theory of J. P. Lesley in his introduction, p. 37, to F. Prime's third report (D3, Second Geol. Surv. Pa., 1878), where he characterizes the Bethlehem gravels as "a high-flood river deposit, or an ancient high-level river-channel deposit."

SUSQUEHANNA PONDING.

This valley is so broad that the only places where damming took place in the Kansan Border are at the narrows near Rupert and at Little Mountain. The ice-dam in the former must have been above 160 feet high, as the Berwick upper sands reach that elevation, and carry glaciated cobbles and boulders.[4] At Nescopeck, opposite Berwick, E. H. Williams, Jr., reported[4] in 1895:

There are three formations in the gravels at Berwick and Nescopeck: first, subglacial till so compact that a pick can scarcely be driven into it. This has a clay base and carries an abundance of rolled stones of all the formations to the north—even granite and anthracite meet in the mass. On this is a bed of modified drift of loose nature and sandy matrix with the same collection of rolled stones, and of equal freshness. In fact there is no difference in the color of the layers. . . . The lower inch of the gravels is a conglomerate with a limonite matrix, where the percolating waters laden with the solution of iron were stopped by the dense till below. Capping all is a layer of unstratified sand that varies in thickness greatly within a few feet, and carries streaks of gravel, glaciated cobbles and boulders at all levels.

This dam was in the narrower and more crooked North Branch of the river: the one in the main stream and far broader valley was low; but sufficient to form a terrace that runs, with slight rise, for 10 miles up the valley of Middle Creek, and for 20 miles up that of Penn's Creek. The latter has a delta 1 mile broad.[5] This low terrace is the nearest approach to a complete valley filling that we shall meet with.

JUNIATA PONDING.

I. C. White[6] was the first to describe the glacial outwash in Juniata Valley, and to call attention to the great distance above the average level of the gravel terrace to which sporadic patches of the same were carried. E. H. Williams, Jr., in 1895,[4] ascribed their origin to ice-dams in the many " Narrows " where this stream has cut through the more resisting ridges which border the trough-like valleys it crosses in its way to the Susquehanna River. The terrace runs with but slight rise far up the valleys of its affluents, and the sporadic gravels are the usual iceberg trash carried on the crest of the released wave when an ice-dam broke, and permitted the ponded water to rush up all opposing slopes and leave its bergs and their burden. This phenomenon occurs nearly every spring in northern

FIG. 1.   Outwash from Lake Lesley, south of saddle, at East Tyrone.

New England streams when the winter ice is lifted by a freshet. Ice-dams are formed at each constriction and sharp bend of the valley, and water ponded to considerable depths, leaving gravel and boulders to be removed by the farmers before cultivation can be undertaken.

Figure 1 shows the character of the glacial outwash carried over the broad and flat saddle at Dix from the Bald Eagle to the Juniata Valley, and dropped at Tyrone as soon as the carrying current lost its velocity of 40 inches per second. The Juniata Valley was never touched by the glacier.

Bald Eagle Ponding.

When the Kansan lobe that moved down the North Branch of Susquehanna River touched the lofty wedge-end, where Bald Eagle and White Deer mountains meet and rise 1,200 feet above the flood plain of the West Branch of that stream, the water of that branch was ponded west of Williamsport, and the lowest point of discharge was the flat saddle at Dix, just above mentioned, into the Juniata Valley. This fixed the surface of ponding at 1,110 feet, and the depth against the glacier near Williamsport at 650 feet.

The gravels to be considered came from the wasting of that part

Fig. 2. End of ridge from Antis Gap, near Jersey Shore.

of the above lobe which had crossed Bald Eagle Mountain, and lay upon the several hopper-shaped valleys immediately south of it. The part of the lobe lying north of that mountain in the Susquehanna Valley between Williamsport and Lock Haven, and in the northern part of Bald Eagle Valley, had been cleared away by the torrent sweeping over the Dix saddle into the Juniata Valley, carrying ice-bergs and gravel, as just described. There was also a considerable discharge of the ponding through the marginal canyon between the glacier and the complex of ridges between Bald Eagle and Jacks mountains.

Figure 2 shows a sausage-shaped ridge of outwash from the wasting glacier in Mosquito Valley, formed by a narrow torrent sweeping through Antis Gap in Bald Eagle Mountain, and drop-ping its burden as its velocity was checked, and its course changed to that of the slow movement of the deep ponding towards Bald

FIG. 3.   Detail of cutting in ridge from Antis Gap, showing rough assortment of strata.

Eagle Valley. Mosquito Valley has a limestone floor and a high ridge-rim of Oneida. The gravel ridge is composed of these, and rises abruptly from the level Susquehanna Valley like an island from

a calm ocean, and bends up stream to show the above movement. It is so large that it has forced the river to make a loop 1 mile to the north of its straight course in order to pass around it, and a remnant exists near its former end as an island 1 mile long. Figure 3 shows the rough assortment of fresh Oneida sandstone and limestone in the dark and fully decayed preglacial surficial mantle of Mosquito Valley. Smaller ridges are found to the east, and opposite similar gaps in Bald Eagle Mountain, composed of similar materials from smaller hopper-shaped valleys. Excepting the most eastern, they bend up stream with the reversed current: the other bends down stream with the discharge through the marginal canyon. All have forced the Susquehanna to make loops to the north to pass around their ends.

The flood plain of this stream is here composed of rocks between the Lewistown limestone and the Pennsylvanian. It is evident that these ridges of entirely underlying measures are not part of a complete valley filling subsequently excavated; but are like the long ridges in the Lehigh Valley, dropped in deep ponding as soon as the velocity of the carrying torrent was sufficiently checked.

PART TWO.

Allegheny Pondings.

Introduction.

We note from what has been described above that ponding may be caused by stream reversal by glacial agencies, and by ice-dams. Permanent stream reversal is brought about by the trenching of the col or saddle in the watershed of the reversed stream to a depth sufficient to ensure the permanent discharge of the accumulated water after the wasting of the glacier which caused the original ponding. Secondary pondings, thereafter, are formed by bergs, as in the "Narrows" of the Delaware, the North Branch of the Susquehanna, and the Juniata.

Figure 4 follows Leverett's Fig. 1[2] in the arrangement of the three river systems that now make up the Allegheny River. Instead of " Old Upper," " Old Middle " and " Old Lower " Allegheny, these

systems are called Allegheny, Tionesta, and Clarion, from the prominent streams which compose them. Of these the last was the predominant stream in Western Pennsylvania. It rose on the plateau of the McKean County highlands in many good-sized feeders which almost met similar feeders of the Allegheny on the north side of the low slopes of the plateau. In the Pittsburgh area it received the waters of the Monongahela and Youghiogheny. Turning westward into the valley now occupied by the Beaver, it received the stream

Fig. 4. Map of Allegheny, Tionesta and Clarion Basins.

now reversed to form the upper part of the Ohio, and in the state of that name it occupied the valley of Grand River. It thus completely encircles the basin of the Tionesta-French Creek stream which partly to-day forms the Allegheny. In Fig. 4 only the portion from its sources to its junction with the latter is shown.

The black indexes mark the places where water was forced over watersheds by more or less deep ponding. Among these places are the four trenched cols: at Big Bend (connecting the Kinzua and Conewango branches of the preglacial Allegheny) ; at Thompson

(connecting the preglacial Allegheny and Tionesta) ; at Foster (connecting East Sandy and West Sandy creeks—branches of the Tionesta) ; at Emlenton (connecting the Tionesta and Clarion basins). The cutting of these to present stream level formed the modern Allegheny River.

An ephemeral connection between the preglacial Allegheny and Tionesta, and which has resulted in the piracy, by the latter, of the headwaters of the preglacial Conewango, occurred during the approach of the glacial margin towards Clarendon, when there was a discharge of the Conewango ponding over the Barnes col and trench into the Tionesta. There was also a trenched col at Titusville; but it had little or no influence in the formation of the gravels to be considered. Its elevation was 1,610.[5]

The following passes and cols enter more or less into the history of the ponding :[5]

A. On the Potter-McKean County Plateau. Discharges from Big Bend Ponding :

> Keating Summit. Trench used by the Iroquois as a portage between the Allegheny and Sinnemahoning basins. Plateau top 2,400 feet; trench bottom 1,878 feet. Immediately east of the McKean County line.
>
> Clermont. Broad shallow pass. Floor 2,068 feet. Allegheny discharge from Potato Creek through Mill Brook into East Branch of Clarion River.
>
> Glad Run. Shallow pass. Floor below 2,100 feet. Into West Branch of Clarion River.
>
> Kane. Forked pass, broad and shallow. The eastern fork into West Branch of Clarion River: the western, into the headwaters of the preglacial Conewango Creek; now, of the Tionesta. Floor 2,025 feet.

B. On the Allegheny-Tionesta Watershed. Discharges from Conewango Ponding :

> Barnes. Trench. Top 1,500; bottom 1,300; filled with 2 terraces of gravel for 60 feet. Preglacial outlet into Tionesta River. Present outlet of preglacial branches of Conewango Creek, dammed by moraine at Clarendon, and now headwaters of Tionesta River.
>
> Thompson. Trench. Elevation considered below. Outlet into Tionesta River after the arrival of the glacial margin at Clarendon.

C. On the Allegheny-preglacial Upper Oil Creek Watershed. Discharge from Conewango Ponding into Titusville Ponding. No cutting or trenching :

Torpedo. Pass. About 1,550 feet. Leads from Brokenstraw to present Oil Creek basins.

D. On the preglacial Upper-Lower Oil Creek Watershed. Discharge of Titusville Ponding:

Titusville. Trench. Top 1,610. Floor with gravel filling. Leads to Tionesta basin.

E. On the East-West Sandy Watershed. Discharge of East Sandy Ponding:

Foster. Trench. Top 1,500. Gravel filling of floor 900 feet. Leads to West Sandy basin.

F. On the Tionesta-Clarion Watershed. Discharge of Tionesta-West Sandy Ponding:

Emlenton. Trench. Top 1,450–1,480 feet. Floor with gravel filling to 860 feet. Leads into a short branch of Clarion River, probably Richey Run, 4½ miles above its preglacial mouth.

G. On Quaker Ridge, between the Conewango and Kinzua branches of Allegheny River. Discharges of Allegheny ponding as the glacial margin moved from the Conewango Valley up the spine of this ridge, parts of which now rise above 2,200 feet—all into the Conewango Ponding. From north of south.

Kennedy. This is the present filled channel of Conewango Creek at the debased end of Quaker Ridge. Top 1,250 feet. Rock floor probably 350 feet lower.

North Bone Run. Trench. Ridge-top about 2,000 feet. Floor 1,582 feet. A branch of the Kinzua, leading to Mud Run.

Bone Run. Trench. Ridge-top higher than last. Floor 1,566 feet. Branch of the Kinzua, leading to Cass Run.

Storehouse Run. Shallow pass. Floor 1,925 feet. Leads to deep trench from the east bank of Conewango Creek.

Reynolds Run. Broad and swampy pass. Floor 2,020 feet. Leads to Ackley Run by trench cut below 1,500 feet for 2½ miles into the flank of Quaker Ridge.

Big Bend. Trench. Top 2,154 feet.[7] Floor probably 1,100 feet. Gravel filling to 1,200 feet. Sheer trench walls rise to 2,040 and 2,060 on opposite sides. The spine of ridge to west averages 2,100 feet. Leads to Conewango Ponding.

Of the above elevations, the only one concerning which there is a difference of opinion is at Thompson. Carll[7] says "at least 1,800," and Leverett,[2] "at least 1,220." The former is too high, as then the

Conewango ponding would have escaped through the Torpedo pass, as soon as the glacier at Clarendon had closed the way to Barnes, and the present Allegheny would now flow up the Brokenstraw Valley to Torpedo, thence through Grand Valley to Titusville, where it would occupy the lower Oil Creek Valley, and join the Tionesta at Oil City. The latter is too low as, with such an elevation, there never would have been a discharge at Barnes at 1,500 feet. Washes about Warren indicate that its elevation is about that of the col at Titusville, 1,610.

PONDINGS IN THE ALLEGHENY BASIN.

These can be separated into those which occurred during the advent of the glacial margin to Clarendon, and to the covering of the Potter-McKean Plateau, and those which occurred during the stagnation and wasting of the ice there. The Barnes and Big Bend pondings were in the former: that at Thompson, in the latter.

BARNES PONDING.

Elevation at beginning was 1,500 feet. Until the glacial margin touched the spine of Quaker Ridge, there was a free passage of all the ponding of the Allegheny Basin at the above elevation to the col at Barnes. The main current passed from the Allegheny up the Conewango to the col. The streams from the Brokenstraw Valley and the short valley with headwaters at Thompson came into the reversed Conewango at Warren, and prevented the distribution of any glacial outwash from the main stream west of Warren. In brief, there was no flow towards Thompson.

Just as the narrow torrents from the hopper-shaped valleys, through the gaps in Bald Eagle Mountain, left long and narrow ridges which rose from the level Susquehanna plain, and without a general distribution of their burden over that plain; so here, a current far broader moved up the Conewango Valley from the ponded Allegheny, and with increasing velocity as the glacier approached. At Warren it received the clear water from the Thompson-Brokenstraw region and passed by Glade, Clarendon, Tiona, Sheffield, to Barnes, where it escaped over the col. At Sheffield it received the stronger flow from the headwaters of the preglacial Conewango, re-

inforced at a later date by the torrent from the Big Bend ponding through the pass at Kane, noted above. We have thus a deposition of sorts of increasing size along this line of current, and only along it, from the Allegheny Valley to Tiona (in general), and Sheffield (with regard to some of the first deposits; but only in very thin beds). None of these deposits came to Barnes and thus into Tionesta River. Of these described by Williams,[5] the *Conewango Clay,* the *Upper* and the *Lower Indian Hollow Sands* were dropped during the discharge of the Conewango Ponding at Barnes, and the *Clarendon Gravels,* at the end—the moraines at Clarendon marking the arrival of the glacial margin of the main trunk on the Pennsylvania Highlands. All are glacial outwashes. Figs. 5 and 6 were
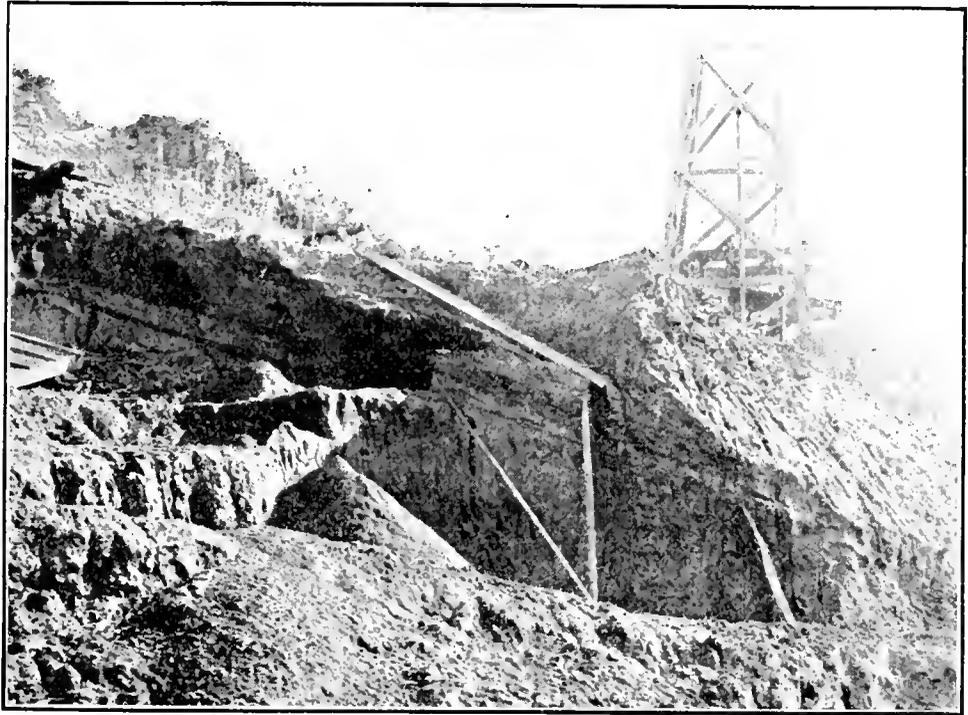
Fig. 5. *Lower Indian Hollow Sands,* east side.

taken from the same set-up, with the camera reversed. They represent the faces of a working in the *Lower Indian Hollow Sands:* the former looking eastward to the back of the Hollow; the latter, westward, toward the Conewango Valley. We are looking at the same strata. In Fig. 5 is shown an area undisturbed by the scour of the flow towards Barnes, though the regular dip of the foreset beds of different color in that direction shows that they were dropped in

deep water by a current moving to the Barnes col, and in quiet water, as shown by the uniform thickness of the beds. Fig. 6 shows a
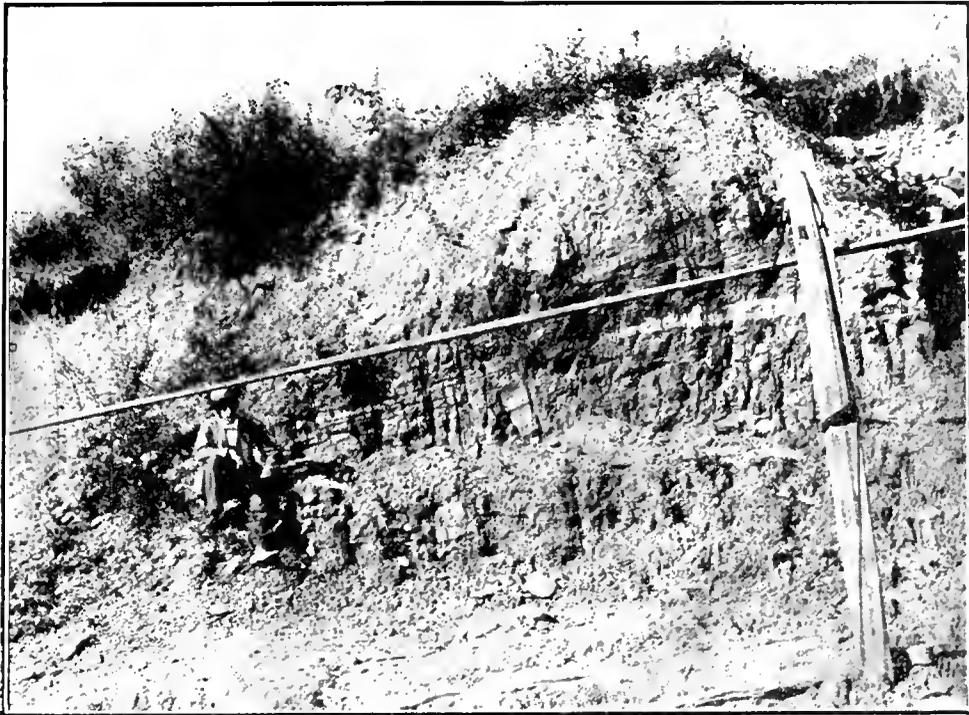
FIG. 6. *Lower Indian Hollow Sands,* west side.

westward extension of the same beds on the edge of the scour of the stream in the reversed Conewango, as each bed thins out, and sometimes completely disappears, as it is influenced by it. In fine, the strata were shaped at that time as we see them to-day, for this is no subsequent cutting down. Each bed becomes thinner, and the dip of the upper layers is steeper than of those at the base. Besides this, there can have been no sculpturing of these beds or of their surface since the deposition of the iceberg clay which is found—with varying degrees of sandiness or of silt—capping everything about Warren, and so down the Allegheny to Pittsburgh. At times the boulders in this cap are of large size, and speak of ice masses floating in deep ponding, as the deposit in which they occur is so uniformly composed of small sorts: at times it is clean silt with little or no larger sorts. Along the Conewango the *Lower Indian Hollow Sands* vary in thickness from 30 to 125 feet, depending upon the conditions of deposition in the different areas where it is found. It rests in the blued, sticky *Conewango Clay,* which carries wood fragments and logs, and is sometimes over 200 feet thick.

FIG. 7. *Clarendon Gravels* on *Upper Indian Hollow Sands.*
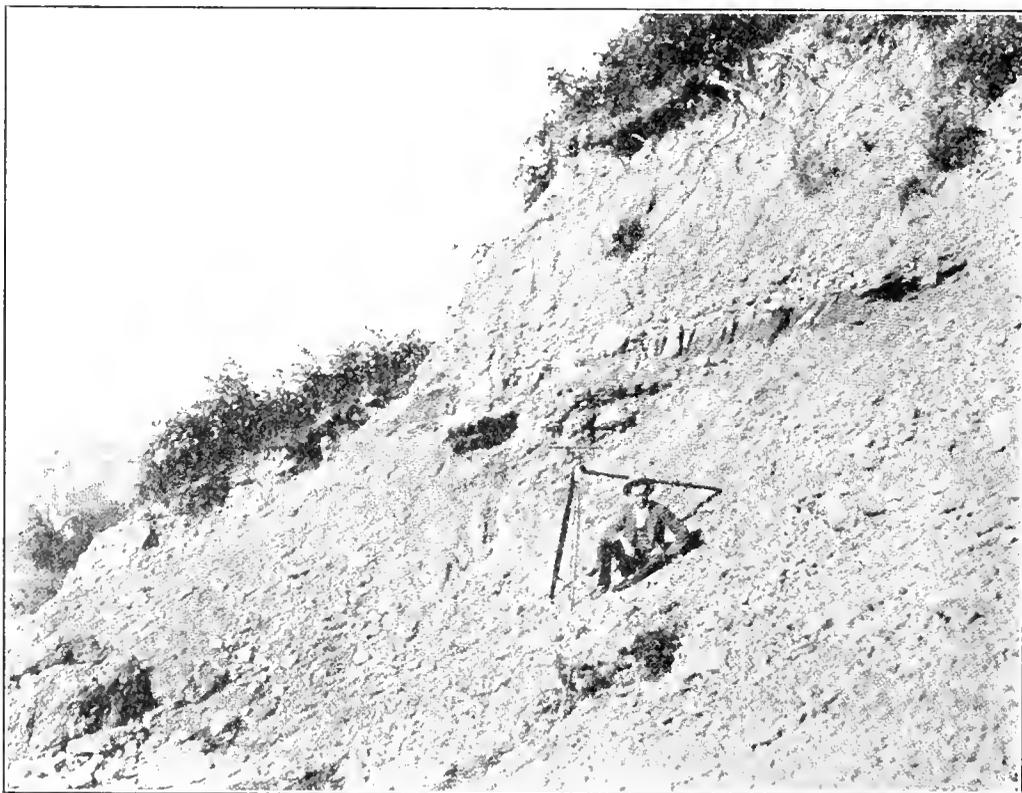
FIG. 8. Southwest face of *Clarendon Gravels.*

Fig. 7 shows the top of the *Upper Indian Hollow Sands,* horizontally bedded, and underlying the *Clarendon Gravels.* Such a deposition of coarse gravel with interbedded quicksand on sands could not have been made in an area of scour. This association, like the thinning out of the *lower sands,* just noted, indicates that the quiet area of Indian Hollow was crossed by a current of less than 8 inches per second; while at the surface of the ponding, 200 feet above, passed a current of over 30 inches per second, carrying the gravel.

Fig. 8 shows more of the southwest face of the working in the gravel bar. The sand stratum shows that the dip was the same as the average of the beds of the *lower sands,* and foreset in the direction of Barnes. The view of the houses of Warren, across the Conewango, in the left foreground, indicates the nearness of the bar to the valley trough, and that it is 200 feet, or more, above it.
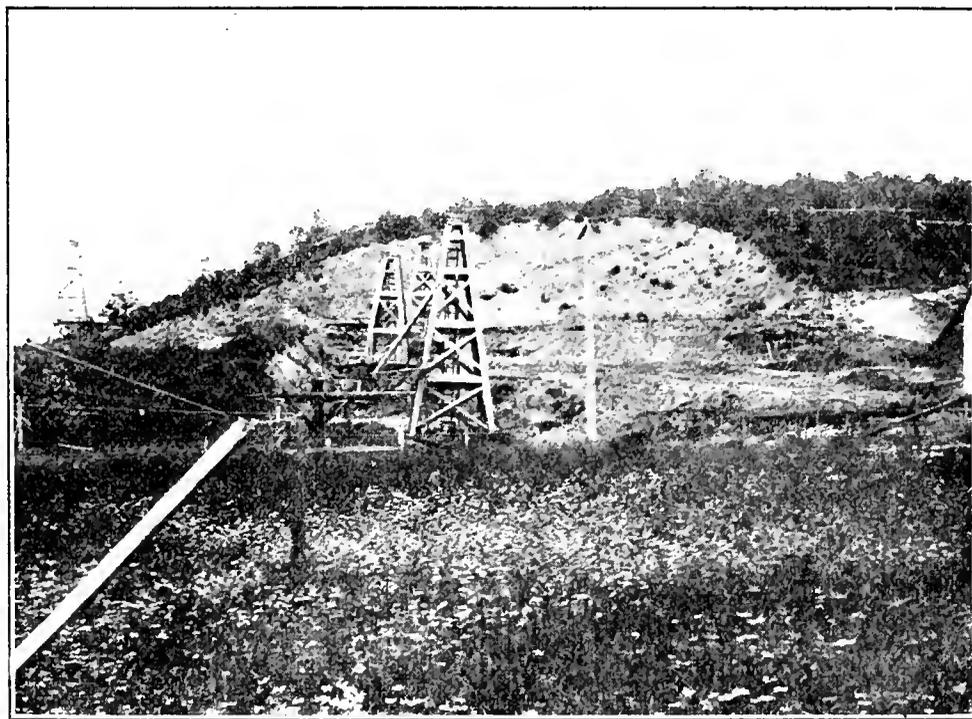
FIG. 9. *Clarendon* gravels on top of *Upper Indian Hollow Sands,* East Warren.

The southern face of the working in this bar is shown in the frontispiece and in Fig. 9. The oil-well rig in the former is the same shown on the extreme left of the latter, and in Fig. 5. This well, and the others in the Hollow, have given a comprehensive idea of

the shapes and thicknesses of the underlying sands and clay, and the depth and slope of the scoured rock floor as it dips toward and beneath the Conewango.

This bar originally stood above the level *upper sands* as do those in front of the Bald Eagle gaps. It stands away from the back of Indian Hollow, across which it originally ran. Its cross-section anywhere shows a cylindroidal surface with the sides coming down rather abruptly to the surface of the shoulder of the offshoot from Quaker Ridge behind which it was dropped, as shown in the frontispiece and in Fig. 8. Its crest merges with that shoulder at 1,488 feet, at a distance 2,300 feet up the slope, and 92 feet vertically above the top of the cutting shown in both figures. It is capped with iceberg clay.

As a further proof that these formations were dropped in deep ponding in sheltered areas along the line of current up the Conewango, and only along that line, we find a similar terrace-bar across Glade Run Valley, since trenched by that stream, consisting of the same succession from *Conewango Clay* to *Clarendon Gravels*. Its axis points up the old Conewango, and toward Barnes, and its foreset dip has the same orientation. G. F. Wright, in 1914,[8] showed in his Fig. 2 a section of this bar 250 feet above the Allegheny River. This is in the shelter of the forked shoulder from Quaker Ridge which forms the southeast side of Indian Hollow, and is thus over the ridge from the bar above described. It has the same sand stratum near its top, and at about the same elevation; but as both bars are bedded with foreset strata, the plane of these interbedded sands at Glade passes in the air at least 1,000 feet above the similar bed at Indian Hollow. We find the same series at Stoneham and at Clarendon, and with the sand stratum near the surface at the latter place, dipping towards Barnes. They are thus not of a general valley filling afterwards sculptured to shape, as shown by the iceberg clap capping about Warren, which was not only dropped in deep water; but showed that the shaping antedated the drainage of the ponding. This last is also shown by the peculiar thin sheets of basal conglomerate with limonite matrix, as noted by Williams.[5]

QUAKER RIDGE PONDING.

This ponding began only when the margin of the main trunk of the Kansan glacier reached a part of the ridge-crest above 1,500 feet, and where there was no depression beyond below that elevation. It was therefore far later than the Barnes Ponding, as that began as soon as the old Allegheny Valley was dammed above that level, and until the glacier reached an elevation on Quaker Ridge also above that level, with no lower transverse troughs, the ponded water to the north of the Ridge poured through the troughs, at or but slightly above 1,500 feet.

It may be asked why no account is taken of the probable lowering of the Barnes trench, as its bottom to-day is at 1,300 feet. The reason is that the greater part of the cutting of that trench took place after the arrival of the glacial margin at Clarendon. It has been said that there are two gravel terraces in the Barnes trench. They consist of pieces of conglomerate, sandstone, red shale and shots of limonite—all local rocks from the McKean County highlands. In addition, it has just been stated that the Indian Hollow bar runs up to the surface of the shoulder of the hill at 1,488 feet. It is safe to say that the Barnes Ponding was not far below 1,500 feet when Quaker Ridge Ponding began.

The Conewango floodplain, at the debased end of the Ridge, is filled between 1,260 and 1,280 feet for nearly 2 miles across the valley, and for about 5 miles along the stream. Two small islands rising 40 feet above the Barnes Ponding represented the Ridge-end. Randolph, Twp., N. Y., is situated at its northern end with a continuous barrier between the Kinzua and Conewango valleys above 1,700 feet; rising in spots above 1,800 feet at the northern end, and to 2,100 at the southern boundary of the township, across which runs the first of the trenches which relieved the ponding—that from North Bone Run to Mud Creek.

The axis of the trench is about Northwest. Its center rises to 1,582 feet, at a point 7¾ miles from the Conewango, and almost exactly on the boundary between Randolph and South Valley townships, N. Y. Its width at 1,600 feet is 260 feet; at 1,800, 1,900 feet. It is nearly 2 miles between the 1,500-foot contours, on a curve of

13,500 feet radius. The wall of the stoss (southern) side rises 520 feet in one third of a mile, and reaches 2,100 feet in a long hill of 4 miles between the 1,500-foot contours. Its southern side drops to the trench from Bone Run to Cass Run. The summit of the latter rises to 1,566 feet, with a length of 1¾ miles between the 1,500-foot contours. The two trenches are about 1 mile apart: the latter curving in an opposite direction from the former, with a direction mainly westward. Its width at 1,800 feet is the same as that of the northern one, and for over 1 mile its width at 2,000 feet is less than three fourths of a mile. Its steepest wall is where the southern side is crossed by the boundary line between Chautauqua and Cattaraugus counties. Its rise is 580 feet in 1,300.

Thence southward into Pennsylvania, through Warren to Mc-Kean County, the crest of Quaker Ridge falls below 2,000 feet only in two places, where narrow passes lead from the South Branch of Sawmill Run—the northern, to Frew's Run, with floor about 1,970; the southern, to Storehouse Run, floor about 1,925, leading to a considerable trench which opens on the Conewango floodplain just north of Ackley.

After the covering of these the ponded water escaped at many places over the somewhat irregular, but level, crest of the Ridge—all above 2,020 feet—and the streams were gathered into four main flows, which passed through the troughs of Jackson, Ackley, Hatch, and Glade runs. With such distribution of power the trenching is long and shallow, and of note only at the lower parts. The elevation of the ponding is now above 2,020 feet, and slightly over 500 feet above that from Barnes.

BIG BEND PONDING.

The overprint on the topographic quadrangle of Olean, N. Y., in the envelope attached to the back cover of Leverett's Monograph,[2] seems to confirm Carll's[7] elevation of 2,154 feet. Small areas rising above it are marked "Driftless." Larger ones away from the scour of the marginal canyon against the north side of Mount Hermon, which also rise above it, are enclosed and marked "South Edge of Ice," "Glacial Boundary," and "Border of Glaciation."

H. L. Fairchild[9] describes ponding in the Genesee Valley forced by the glacial lobe up that area, over the Potter County Highlands, and to the southern border of McKean County, which reached even higher elevations. It poured into Allegheny Valley with more or less deep and broad trenching at 1,494, at 1,600, at 1,692, and at 2,068 feet, and over the Potter County Highlands at 2,174, at 2,228, and at 2,252 feet.

The Big Bend Ponding poured over the McKean County Highlands at many places, as can be noted from the proximity of the feeders of the Allegheny and the Clarion on that plateau—the headwaters of several being about 300 feet apart. The greatest delivery on the east was through the deep trench at Keating Summit with bottom at 1,878 feet into the Sinnemahoning. Torrents came across into the feeders of the Clarion, as will be noted below. A strong flow came into the headwaters of the old Conewango: sufficient to keep the flow from Warren to Barnes ponded between Clarendon and Sheffield, and to prevent the slightest bit of glacial outwash to pass over the Barnes col into the Tionesta River. The Keating trench, and passes at Clermont, Glad Run and Kane, have been described above. These were the most important; but there seems to have been a general movement across the plateau when the margin of the main trunk of the glacier reached Big Bend, and the Genesee-Sinnemahoning lobe closed the trench at Keating. Williams describes the results[5] in the bars, high terraces, and areas of sporadic gravels in the Sinnemahoning and Clarion basins, and, as at Clermont, even on the plateau. Carll[7] reports 43 feet of stratified glacial outwash in the headwaters of the West Branch of Clarion River. The floods seem to have carried ice-cakes, as we find boulders in the stratified gravels along the Instanter Branch of that stream.

It is Leverett, however, who describes, p. 129,[2] the tremendous trenching of these floods from Big Bend Ponding, with their great elevation:

At the mouth of the Clarion a broad gradation plain comes in from this (Clarion) valley and continues down the Allegheny to its mouth. This has been trenched to a depth of about 200 feet below the level of the old rock floor. The trench or inner valley is usually about one half mile in width
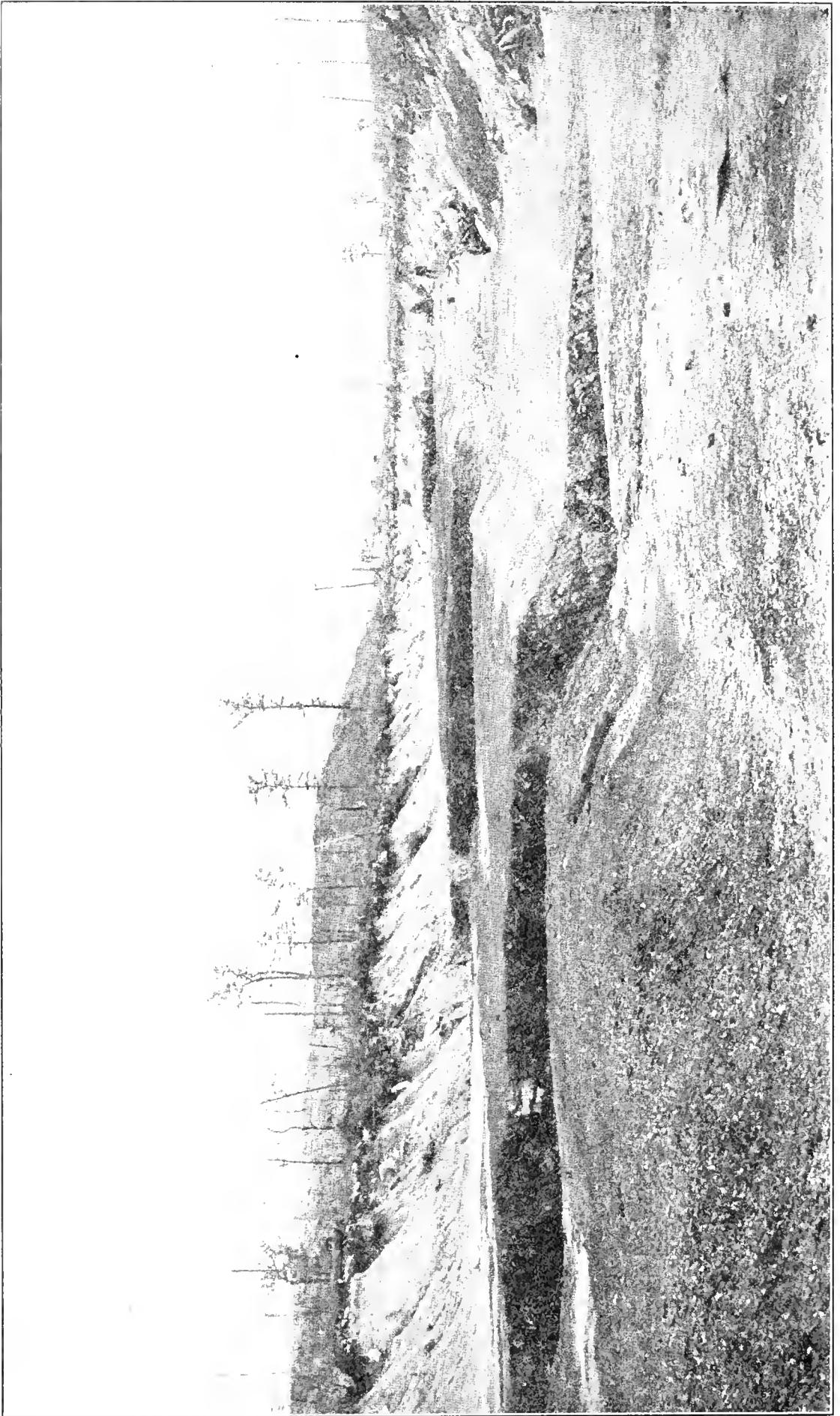
Fig. 10. North outcrop of Mammoth Bed, Morea, Pa.

though it increases to nearly a mile near the mouth of the stream. At the level of the gradation plan there is a general width of about 1 mile. This gradation plain is capped by a deposit of sand and gravel, with an average thickness of perhaps 40 feet, that serves to accentuate the terrace-like appearance, for it fills up small trenches that have been cut in the gradation plain prior to the gravel filling.

This statement, and the description of the preglacial Clarion above, prove that the Clarion was the preglacial dominant stream in Western Pennsylvania. The above trenching cut its rock floor so far below those of its affluents that they are strongly refreshed for a few miles from their mouths, and seem to leap into it. This applies also to the Allegheny. The recency of the Clarion trenching is indicated both by the freshness and steepness of its rock walls. Leverett concludes his description of this trench with the words:

It is hardly necessary to state that just above the level of this gradation plain the bluffs are far more worn and receding than in the inner or canyon valley lying below it.

This freshness of the Mississippian-Pennsylvanian measures along the Allegheny is paralleled in the denser outcrops of the same in the Anthracite basins—notably at Morea. Fig. 10 shows that the resistance of the anthracite bed is greater than that of the top rock, and Dr. Kiefer's analyses[5] tell that the carbon ratio (38.37) of the beautifully polished surface was the highest of all the samples: that samples taken 60 feet below the surface came next with 38.20, and the mealed anthracite, ground up by the ice and found directly against the polished surface and below 8 feet of gravelly drift, showed 11.05 and 11.18. This is vastly different from the "black dirt" of an unglaciated outcrop with its low ratio of 1.23. Dr. Barrell[5] reported, in strength tests:

Samples near the surface of North Crop are as strong, if not stronger, than those at a depth of 55 feet. Sample No. 3 taken 250 feet below surface was an especially hard, solid piece of coal, and gave fairly uniform results; but its average is not different from that of the more fissile samples taken at the North Crop.

This bears upon the finding of fresh pieces in the Kansan gravels, and especially of crystallines from the preglacial surface which were given the usual concentric shells of weathering before incorporation in the glacier; but which have been irregularly gla-

ciated, like the cobble under the arrow in Fig. 11, which has been cut on the right side until the fresh, white nucleus shows. These facts force us to choose between a slowness of rock decay since Kansan times that seems negligible, or a recency of that time ; as
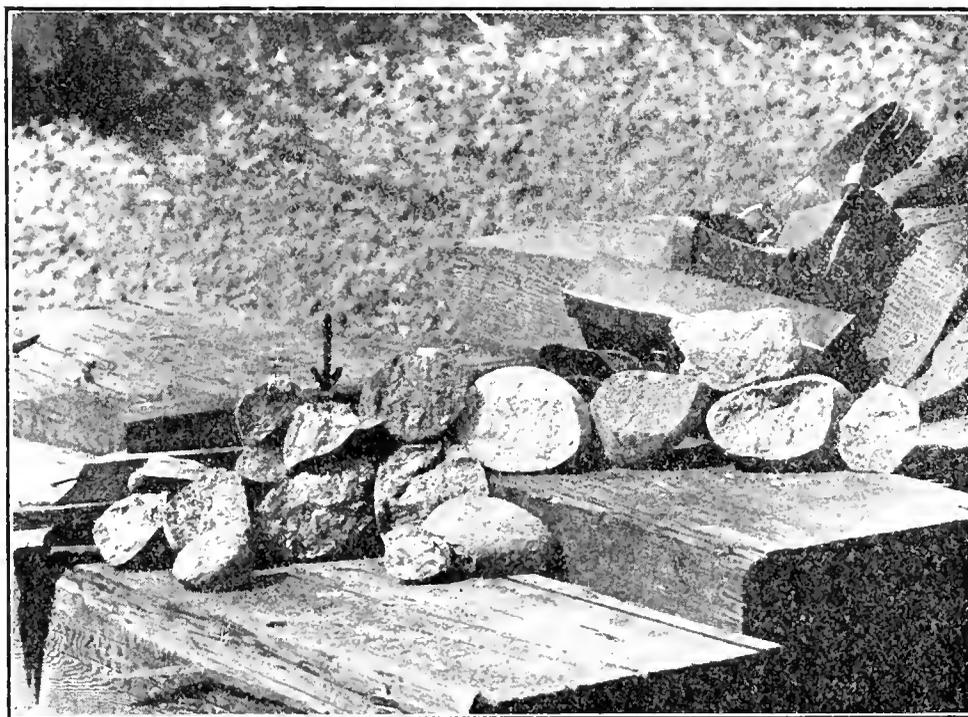
Fig. 11. Crystallines from South Warren terrace-bar, showing mixture of decayed and fresh pieces. Cobble under arrow has fresh (white) nucleus exposed by rolling.

the trenching of the Clarion and the deposit of these fresh rocks occurred when the glacier had spent its maximum strength in surmounting the Pennsylvania Highlands. Thereafter began its stagnation and wasting about Warren.

THOMPSON PONDING.

Elevation at beginning 1,610 feet. The glacial margin had spread over the entire Conewango Valley, and was over, or near Thompson col. Grand Valley and Titusville were covered. The water level about Warren rose over 100 feet, and into it tumbled the torrent at work excavating Big Bend Col which, at first, had a fall of over 650 feet, and, when the Thompson level was formed, continued with 500 feet of head. The glacial energy was gone and there was no more advance over the Highlands.

The torrential fall over Big Bend Col speedily tore a canyon through the stagnant ice in the Conewango Valley as directly as possible to the Thompson outlet: removed the deposit of *Conewango Clay, Upper and Lower Indian Hollow Sands,* and *Clarendon Gravels* from Glade to the mouth of Dutchman's Run (in the old Conewango channel), and the scour operated so far up the valley of the Run that it gave quickness to the sands in the formation at Stoneham, causing them to run out and the *Clarendon Gravels* there to drop on top of the *Conewango Clay.* Williams has shown[5] that the loss of the 100 feet of *Indian Hollow Sands* here, and so near the apex of the gravels at Clarendon, at 1,513.32, permitted a shifting of the latter towards Stoneham, and a dropping from their probable elevation of such a height above the crest of Thompson Col that they prevented a return to the Barnes discharge until the former col was trenched below 1,500.

In addition to opening a canyon through the stagnant ice in the Conewango Valley, the Big Bend torrent cut off 1,000 feet of the west end of the ridge between Morrison and Ott runs, and 1,500 feet to half a mile from the one between the latter and the old channel of Brokenstraw Creek, where it turned north to join the Cone-
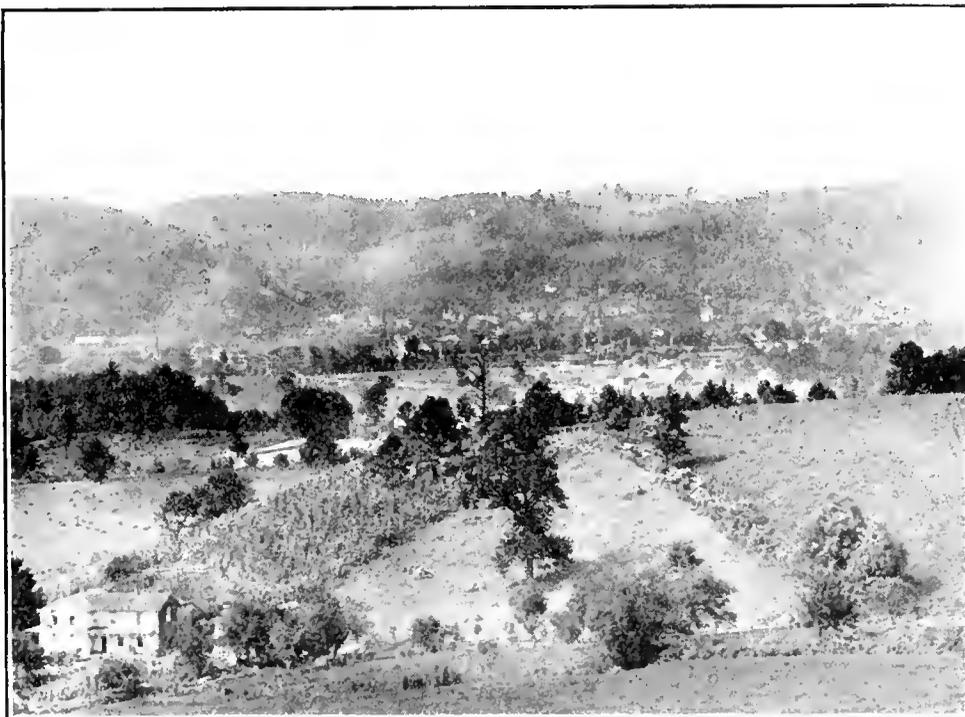
FIG. 12. *Early Big Bend gravels,* Oakland bar, South Warren.

wango.[5] The sheer walls of this cutting are shown along the railroad across the Allegheny from Glade. In this canyon were dropped some of the deposits described below, and others were dropped after the greater clearance of the glacier from the valley. Williams[5] has called these the *Early,* the *Middle,* and the *Late Big Bend Gravels* of the *Late Fluviatile Period,* as all the prominent deposits along the Allegheny Valley are associated with ponding, and with deposition by currents passing through stagnant water.

All of these deposits show foreset bedding dipping towards Thompson, and the earliest is the high, long, and narrow bar standing out into the level plain, on which Oakland Cemetery is situated, south of Warren and of the Allegheny River. This is similar in
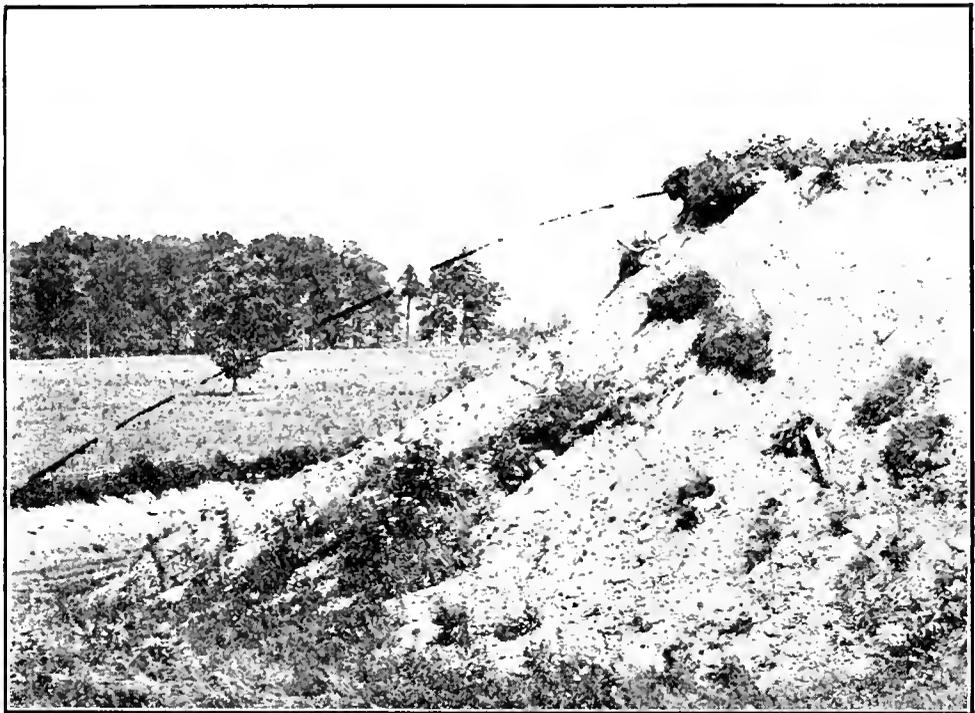
FIG. 13. Western end of South Warren terrace-bar, showing shaping before deposition of *Leverett* clay.

appearance and origin to the bars in front of the gaps in Bald Eagle Mountain (cf. Fig. 2). It is capped with iceberg clay, and its top has the elevation of the *Upper Indian Hollow Sands,* 1,322 feet. The old gravels in its composition are the *Clarendon Gravels* swept from the valley of Brown's Run, from the area where the Conewango channel was crossed by the torrent, and from that channel

for some distance towards Stoneham. They are smaller than the average of the pieces at Indian Hollow and at Clarendon, as would be the case after such rough rearrangement, and they are mixed with an equal proportion of local pieces eroded during the trenching described above. (Figure 12.)

Fig. 13 is the end of a bar composed of the *Middle* and the *Late Big Bend Gravels,* of lower elevation than the Oakland Cemetery bar. The worked-over crystallines in its composition are very much comminuted and among them are rocks foreign to the *Clarendon Gravels;* but found north of Big Bend. This indicates such a trenching of the col there that the scour reached to the Kinzua Creek bottom. There are also large pieces of local rocks—both old and fresh—which are absent from the older gravels. It is capped by iceberg clay, which is from 10 to 12 feet thick in places, and varies from a clayey matrix to nearly clean silt as it nears the end of this bar. The figure shows the dropping of the bar-end to the plain. This shaping and the decrease to one third of the thickness one half mile east, shows the increase in the scour of the current, as does the absence of the clay from the sandy cap. This latter was dropped after the shaping, and can be seen at the level of the plain across the country road. None of these Warren formations are remnants of a complete valley filling afterwards excavated. This closes the various pondings of the old Allegheny River.

TIONESTA PONDINGS.

Emlenton-Foster Pondings.

Although the Emlenton Col is below that at Foster in the present Allegheny Valley, it was the first to be trenched. Its original elevation is inconsequential to this discussion, though it was below 1,500 feet, and probably between 1,430 and 1,480 feet, as shown by beach lines about, and north of Warren. It is on account of these, and of some sporadic gravels in the old West Sandy Valley that its elevation is a matter of interest.

Although the glacier crossed the mouth of the old Tionesta River ages before it reached Franklin, and though there was probably ponding in its valley from an early date, the discharge was

through a marginal canyon at a low elevation, and westward into the ponding of the old Clarion, as there is such a rapid westward slope of the region that only within twenty miles *below* Franklin, in the old Tionesta Valley, do its valley crests fall below 1,400 feet. Thus, though the ponded water may have been backed up the old West Sandy Valley against the Emlenton Col for thousands of years, with increasing depth, it did not flow over it until the glacial lobe passing down the western border of Pennsylvania had cut off the escape of the ponding at lower levels. As the side movement of a lobe-margin up hill is slow in comparison with the onward one of its front down or along a slope, it is safe to take even smaller figures for yearly progress than those suggested by Dr. Upham[10] at Toronto in 1913, and take 15 feet per year as the average progress of a margin constantly scoured by a torrent, and 20 miles from the mouth of old West Sandy Creek, as the position of the glacier when the flow over Emlenton Col began. The margin must move 22 miles to close that mouth, and with constant progress at the above speed would require over 7,000 years before the Tionesta Ponding would flow over Foster Col. As the trenching here is below present stream level, and the stream flows over gravel, it is evident that another long period intervened when the floods over Foster Col poured into West Sandy Valley and over Emlenton Col, and before the former col was fully trenched. We are now prepared to understand that, long before this happened, the Emlenton Col and the portion of West Sandy Valley between it and the Foster trench had been cut down to their present levels. And yet there was a ponding of the Tionesta against Emlenton Col after the Foster trench had been fully sunk. There was thus a first and second Emlenton Ponding, with the Foster Ponding as an episode between that reached far up the old Tionesta. With the first we have no concern.

Foster Ponding.

Elevation at beginning 1,500 feet. The trench walls on both sides rise to this elevation. Reddish iceberg clay with scanty gravel and cobbles is traced continuously to near this elevation on the hills about Franklin and at Oil City. Just below this mark where the country road from Franklin to Mays Mills dips down to Sandy

Creek in a sandy wash, there was found a cobble of red granite with quarry face and edges; but so pulverulent that it crumbled between the fingers. In the same wash were pebbles of fresh crystallines. These indicate deep ponding and floating ice. At Salamanca, Olean, and other places along the old Allegheny Valley are broad terraces at 1,500 feet. There are beach lines in the affluents of Kinzua Creek at this elevation, and indications of ponding at this level about Sheffield and Clarendon.

Second Emlenton Ponding.

The damming probably took place between this place and Foxburg, where the stream passes through the ridge with crests above 1,500 feet. The elevation of the water was between 1,430 and 1,480 feet, as shown by washes, beach-lines, etc., in the vicinity and at Oil City, Sheffield, and in some of the Kinzua affluents. At Roystone there is a swampy fan running from 1,430 to 1,480 feet.

Our study will be limited to the sporadic gravels in the West Sandy Creek Valley. These were thought to be remnants of a complete valley filling, since excavated, as stated by G. F. Wright in 1894.[1] This theory he abandoned—retaining however the idea of a complete valley trenching to the present rock floor before their deposition. Leverett, in 1902,[2] held the same view as to the trenching; but thought the gravels remnants of a complete filling.

There are three terraces of these gravels, and Leverett states:

> In several places, notably at the bends of the river at Brandon, at a point 2 miles below Brandon, at Kennerdell, at Black's (Winter Hill Station), and at Emlenton, there are deposits on the face of the gorge extending from the river's edge up to heights of 200 to 300 feet or more above the stream. The occurrence of this gravel at low places can not be accounted for by creeping or landslides, since in some places, notably at Kennerdell and 2 miles below Brandon, the gravels show clearly by their situation and bedding that they have not been disturbed since the stream deposited them.

The sole criticism is against the use of the word "gorge" for the low slopes on which the gravels lie at Brandon and at Kennerdell. At the former the slope varies from 7 degrees at one end to 16 degrees where it ends: at the latter the slope is 10 degrees. As would be the case when a torrent laden with glacial outwash trenches so tortuous a valley as that of West Sandy Creek, there would be

a working outwards on every curve, with the result of making the bends more pronounced, and of making a steep stoss-side against which the torrent would strike, and a low slope where scour did not obtain. These gravels lie on these low slopes where scour did not obtain during the trenching of the valley, and where it did not obtain when the far slower current dropped the sands and gravels that we are considering. Thus, though at Brandon and Kennerdell the gravel-covered slopes are at the above low angles, the opposite, or stoss sides of the valley rise almost from the stream edge at angles of 45 degrees at Brandon, and of 42 degrees at Kennerdell.

From the above quotation we learn that the gravels are sporadic and not continuous: that they have been disturbed by neither creep nor landslide since their deposition and, since they extend " from the river's edge," that the present channel was fully excavated before their formation. Their appearance at Emlenton tells us also that the col there was trenched to present stream level.

A consideration of the topography of the region is essential to the discussion. In the Brandon-Kennerdell area the 940-foot line crosses the Allegheny stream-level 1 mile from the western end of the trench at Foster, and the same distance west of Foster Station. There is a 50-foot terrace of gravel at Foster. The 920-foot line crosses the stream where Pine Hill Run enters the northern horn of the ox-bow bend above Kennerdell, and over 2 miles north of Kennerdell Station. At the Run mouth there is a steep stoss-side to the Allegheny Valley on the left, and against which the torrent strikes almost at right angles. This side rises from stream-level at an angle of 45 degrees, with but a slight shelf on which the railroad is built. The opposite side of the valley has the usual low slope, with a fine terrace, and a high bar like those above described. At the top of the steep stoss side there is a narrow level crest of the ridge about which the stream winds. The elevation is 1,400 feet for 2 miles from the end. From this runs downward the low slope on which the Kennerdell gravels are found. The 900-foot line crosses the stream 1 mile south of the southern horn of the Kennerdell ox-bow. The gravels at Brandon come down to the level of 930 feet; at Kennerdell, about to 914 feet.

The effect of the torrent from Foster upon the opposing valley

wall of West Sandy Creek, where a sharp ox-bow curve was made to turn it upon itself in order to pass to Emlenton, is seen in the great valley width, which is six times that at Kennerdell. With but slight narrowing this width extends southward to Brandon. If ponding obtained hereabouts it is evident that the velocity of the current through it must have been proportionally slower at Brandon than at Kennerdell. That there was ponding is shown by the classification of the pieces in the glacial outwash, and by the iceberg clay capping.

There are larger pieces in the Brandon gravel than in that at Kennerdell, and the silty cap at the former is 8 feet thick, against the 2 feet at the latter, measured at the same distance above the stream. The smaller sizes are also carried to a higher elevation at Brandon. The slower current there would produce a more profound slackness of the water in sheltered areas than at Kennerdell, and there would be less movement of the surface. It has been noted that the shoulder of the ridge which holds the Kennerdell gravels rises to 1,400 feet for 2 miles form its end. That which sheltered the area at Brandon rose slightly above an average of 1,450 feet, and in one place above 1,500 feet. The level of ponding was between 1,430 and 1,480 feet. The stream flowed through this along the broader channel above Brandon, and parallel to the axis of the ridge just described, which rose to or above the surface of the water. At Kennerdell, on the contrary, as the current swept about the bend where Pine Hill Run enters, it struck squarely against the stoss side of the ridge which shelters the Kennerdell area, and its upper 30 to 80 feet crossed that area directly. Only its profound depths would be suitable for deposition.

We are now prepared to appreciate why the coarse gravel extends at Brandon between 930 and 1,200 feet: at Kennerdell, between 915 and 1,000 feet. The fine gravel with 50 per cent. of silt, which tells of a slacker water, extends at Brandon between 1,200 and 1,300 feet: at Kennerdell, between 1,000 and 1,200 feet. The wave-action upon the thin drift sheet is marked at Brandon up to 1,400 feet; at Kennerdell all above 1,300 feet is swept away. Lastly, the iceberg silt, which caps everything, and which marks the slowness of the current at this end of the wasting of the Kan-

san glacier, is very sandy and, as stated above, is 8 feet thick at track level at Brandon; 2 feet thick at same level at Kennerdell. These two places are indicated on Fig. 4 by the blunt arrows opposite the letters (*ND*) in the name West Sandy Creek.

FIG. 14.   Drift overlaid by assorted gravels, Brandon.

It is generally acknowledged that the glacial margin lay at or just east of the Allegheny Valley at these places. Figs. 14 and 15 were taken at track level, and thus at the same distance above stream level. The former shows drift overlaid by gravel at Brandon. The drift here is spared in the more sheltered area. The latter shows the entire thickness of the gravel at Kennerdell overlaid by the 2 feet of sandy iceberg capping.

These are no remnants of a complete valley filling. The only example of this exists in the abandoned part of the valley of West Sandy Creek between Polk and its mouth at Takitezy. Its highest point is near Niles, just below 1,160 feet. These gravels are like similar ones dropped in the quiet areas behind the protecting shoulders of ridges about which the stream winds. The only interesting point about them is that they seem to have been the expiring effort of the wasting Kansan glacier in the Allegheny-

Tionesta basins. When the ice-dam immediately below Emlenton was finally broken there was no renewal of ponding at such an elevation.

FIG. 15.　Thinness of *Leverett* clay over assorted gravels, Kennerdell.

CLARION PONDING.

The margin of the Kansan glacier covered the mouth of Clarion River. The highest elevation of overwash gravel there is 1,230 feet; the highest point of the thin drift is at least up to 1,400 feet. In this are coal flakes carried above the outcrop, fresh fossiliferous Chemung, fresh black gneiss, and completely decayed basalt. The entire valley of the reconstructed Allegheny from its source to Foxburg was beneath Kansan ice.

The sporadic deposits in this ponding vary in elevation on either side of the stream at a given point, just as they do to the north. Opposite Indian Hollow, on the hill at Warren, there are no gravels of Kansan origin. At Tidioute there is 120 feet of difference in the gravel tops; at Foxburg, 100 feet.

There is also a difference in the character of the gravels on opposite sides of the stream. At Red Bank the west side shows a narrow

valley and a slope washed by the scour; more assortment of the gravel: not so many glaciated boulders of large size. The east side shows a wide valley and protection from current; more mixture of the gravel: many large glaciated boulders.

The ponding here was at least 200 feet below that above Emlenton, and high gravel ridges are found in the slack areas behind projecting shoulders of the high bluffs about which the current wound through the ponding. There are three such near Monterey, at varying elevations.

The iceberg clay is again the deciding factor. At the last named place it is 10 feet thick and with large boulders. The same are at Blairsville Intersection, at Red Bank Junction, at Fairmount, and they run to the tops of the ridges under conditions that show that they are not a subsequent wash. The Kiskiminetas Valley, and that of Red Bank Creek show terraces, bars, rock masses as large as a small house, in clay with boulders and local gravel of sorts, and all unite to tell of ponding in which Kansan gravels were dropped.

Conclusion.

The surface of Northwestern Pennsylvania resembles that of a flat and much etched cone, with axis at Kane, and a fall of 1,000 feet to Foxburg in 42 miles on a southwest course. The Kansan glacial margin spread southwestward about this apex and lay about in the meridian when it crossed the mouth of Clarion River. The passage of the lobe southward along the western border of Pennsylvania seems to have relaxed the activity of the portion capping the Highlands of the state. The discharge was along the marginal canyon between the glacier and the rising surface to the Alleghany uplift. This canyon rested at times across the watersheds at Big Bend, Thompson, Titusville, Foster and Emlenton, and induced such depth of trenching of cols that the subsequent ponding was able to complete the work.

The clearance of the region from the Kansan glacier began at the McKean-Potter Highlands in the Conewango Valley about Warren. The trenching of the canyon therein was accompanied by the settlement of the ice towards that valley trough, and the calving

of bergs into the torrent passing through. These grounded and packed wherever a chance offered, and there were many chances in so tortuous a valley. Pondings occurred after cols were degraded, and as a finishing clearance from the wasting glacier, the final ice-dams were comparatively feeble and against weak currents which brought the last of the washings of the thin drift sheet, and floated the remnants of the ice-cakes to form the clayey-sandy-silty capping which covers everything below the ponding level.

Because the ponding from the untrenched cols extends northward at high levels, and because we find this universal capping, it does not follow that the boulder clay was dropped everywhere at the same time. Its wide variations between clay, silt, and sand, as well as the great difference in size of the cobbles and boulders included, prove that in each portion of the Allegheny Valley it was merely the final episode of the clearance of that portion, and as the ice-dam at a given point was finally carried away, whatever ponding extended over that point was from a lower dam to the south.

This is proved to have been the case in the Allegheny Valley. The ice-dam just below Emlenton was not the sole one in that valley. Those to the north would be formed between walls reaching to a higher elevation: those to the south to a lower one. The sporadic deposits would be carried to elevations averaging above or below a theoretical gradation plain; but with wide variations therefrom on opposite sides of the valley at a given point that would not obtain in a complete valley filling. There is more adherence to such a gradation plain in the glacial outwash in the Juniata, as shown by the extension of the river terrace up the valleys of the affluents, and the strictness of the average elevation of 80 feet above present stream level. It is safe to conclude that the Kansan gravels in the valleys of the Lehigh, the Susquehanna, the Juniata, and the Allegheny were dropped and sealed in their present shapes during the final clearance from the Kansan glacier. There was no complete valley filling.

It seems also that this conclusion can be extended to gravels of uncertain or disputed origin in this and other countries. We have seen valleys never touched by the glacier, but adjacent thereto, and separated by a high watershed therefrom, invaded by torrential

flows which made deep trenches, and deposited stratified outwash and local gravels, as along the Juniata and the Clarion. It is permissible to ask whether these uncertain gravels, which are in unglaciated areas, but contiguous to possible glacial pondings, may not have had an origin similar to those under consideration.

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THE PARALLAXES OF FIFTY STARS (SECOND LIST) DETERMINED AT SPROUL OBSERVATORY.

By JOHN A. MILLER,

WITH THE COÖPERATION OF

JOHN H. PITMAN AND HANNAH B. STEELE.

(Read December 5, 1919.)

I have given in the following pages the data of observation, the data of reduction and the reductions necessary to determine the parallaxes of fifty stars. It seems unnecessary to describe either the instruments or the methods employed in the work, further than to say that the intsruments used are the same that were used in determining the parallaxes of the first list published by the observatory in 1917 (Sproul Observatory Publication No. 4). The fields are photographed with a 24-inch visually corrected refracting telescope on Instantaneous Isochromatic plates. A ray filter which cuts off the violet and the red rays is placed very near the plate. These plates are measured and reduced as described in the publication referred to. The scale on the plate is $4''.685$ to the quarter millimeter, the value of one turn of the screw on the measuring engine.

These results have been obtained through the efforts of several persons. The work has been done according to plans of the writer. Those participating in the work are: Professor John H. Pitman, Miss Hannah B. Steele, Dr. Samuel G. Barton, Reverend Walter A. Matos, Miss Marie S. Bender, and Miss Caroline H. Smedley. No one of us has been free to devote his entire time to it. I believe, in the body of the text, I have given specific credit to each for the part of the work he has performed. The reductions and many of the measures, as well as the routine work of marking the plates and keeping the records was performed by Miss Steele until 1916 when she went to Yerkes Observatory. Miss Bender did this work the following year and Miss Smedley, since the summer of 1917, has given much of her energies to the same work.

Some of the fields of comparison stars have been selected in ac-

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cordance with the scheme described in Sproul Publication No. 4, (p. 10 *et seq.*). Other fields have been selected in the usual way, *i.e.,* the comparison stars were selected because of their location and brightness, the ideal being in every case to select stars of approximately the same brightness and to reduce the parallax star to the same magnitude by the occulting disc. In the final table of this paper, which contains a summary of the preceding results, I have marked with an asterisk those stars whose comparison fields were selected by the first method. I propose a little later to discuss more fully our experience with this method. In the detailed results which follow there is given for each star its *B.D.* number together with some other ordinarily used designations; its position for the epoch of 1900; its magnitude; its proper motion; and its spectrum. The magnitude and spectrum are taken if possible from the Annals of the Harvard College Observatory, Volume 50. The proper motions are taken, with few exceptions from Boss' Preliminary General Catalogue, or from the Cincinnati publications.

Two tables are given in connection with each star. The first contains the necessary observational data, and the quantities needed for reduction. The initials in columns 2 and 9, have the following signification: B. denotes Barton; Be., Bender; M., Miller; Ma., Matos; P., Pitman; S., Miss Steele; Sm., Miss Smedley. T., in column 4, is the time of observation given in 100 days from the mean date of the series; m., in column 6, is the " solution " of the plate given in quarter-millimeters; p., in column 7, is the weight of the plate assigned by the person who measures it. The second table contains the data for the position of the comparison stars measured in equatorial co-ordinates, the diameter of the stars in quarter-millimeters, and their *B.D.* numbers. Following this table are the normal equations and their solutions. The quantity μ in these equations is the proper motion given in seconds of arc per hundred days. *The quantity, π, is the relative parallax.*

No. 1. B.D. — 4°.62. Ho. 212 = 13 Ceti. (0^h 31^m.1; — 4° 9'.)
Mag. 5.24. μ = 0^s.0272; — 0″.018. Spectrum F.

Ho. 212 is a triple star, the measures below refer to the close pair A B, which is a binary system with a period of 6.88 years. The combined image of the pair is sensibly round, and in the measures this image was bisected. It was measured in right ascension. Russell found for this star a hypothetical parallax of + 0″.039. The brighter image, A, has been found to be a spectroscopic binary.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Nov. 17, 1915...	+0 8	P.	—6.25	—0.66	+0.123	1.0	+0.005	P.
Dec. 4, 1915...	1 2	Ma.	6.08	.81	.125	.5	.006	P.
Nov. 19, 1916...	+0 25	M.	—2.57	—0.69	.237	.7	—0.014	P.
Dec. 10, 1916...	0 42	M.	2.36	.85	.232	1.0	.006	P.
Aug. 19, 1917...	+0 15	P.	+0.16	+0.62	.309	1.0	—0.003	P.
Aug. 25, 1917...	0 50	M.	0.22	.54	.316	.6	.008	P.
Aug. 27, 1917...	—1 15	P.	0.24	.52	.304	1.0	+0.003	P.
Aug. 27, 1917...	0 30	P.	0.24	.52	.303	.7	.004	P.
Nov. 5, 1917...	—0 12	M.	+0.94	—0.52	.311	.5	+0.004	P.
Nov. 25, 1917...	+0 45	M.	1.14	.75	.322	.9	—0.005	P.
Dec. 22, 1917...	0 0	Ma.	1.41	.89	.316	.5	+0.007	P.
Jan. 1, 1918...	1 10	M.	1.51	.90	.318	.5	.008	P.
Aug. 14, 1918...	+0 15	Ma.	+3.76	+0.68	.400	.9	0.000	P.
Aug. 22, 1918...	0 10	D	3.84	.58	.393	.5	+0.008	P.
Aug. 22, 1918...	1 5	D	3.84	.58	.406	.8	—0.005	P.

Normal Equations:

$$+ 11.10000\ c - 1.4170\,\mu - 1.0340\,\pi = + 3.2417.$$
$$+ 103.5299 + 13.0930 = + 2.3872.$$
$$+ 5.1344 = + .0841.$$

Solution: $c = + 0″.296.$

$$\mu = + 0″.121 \pm 0″.002.$$
$$\pi = + 0″.048 \pm 0″.010.$$

p. e. unit weight, ± 0″.019.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+138.3	— 97.7	+0.326	0.47	
4	263.4	51.9	.197	0.40	
7	— 71.1	+181.0	.019	0.45	
10	149.7	61.5	.234	0.37	
12	271.0	108.3	.224	0.50	
π	0.0	0.0		0.67	—4°.62

No. 2.   B.D. 37°.175.   μ Andromedae.   (0^h 51^m.2; + 37° 57'.)
Mag. 3.94. $\mu = 0^s.0128; + 0''.027$.   Spectrum A$_2$.

This is one of the first type stars with large proper motion.
Slocum obtained 0".005 ± 0".007 for its parallax. The measures
were made in longitude.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Dec. 7, 1912...	0 0	S.	—7.30	—0.727	+0.053	.8	+0.011	S.
Dec. 9, 1912...	+0 4	B.	7.28	.751	.066	.8	—0.002	S.
Aug. 21, 1914...	+0 20	P.	—1.08	+0.870	+0.127	.8	—0.002	S.
Sept. 5, 1914...	0 10	P.	0.93	.713	.141	1.0	.016	S.
Nov. 20, 1914...	—0 41	P.	—0.17	—0.491	+0.121	.9	+0.003	S.
Nov. 22, 1914...	0 45	M.	0.15	.522	.128	.9	—0.005	S.
Aug. 17, 1915...	—0 49	P.	+2.53	+0.905	+0.136	.8	+0.018	S.
Aug. 22, 1915...	+0 4	P.	2.58	.863	.155	1.0	0.000	S.
Aug. 23, 1915...	—0 39	P.	2.59	.855	.157	1.0	—0.002	S.
Aug. 25, 1915...	0 40	P.	2.61	.836	.152	1.0	+0.003	S.
Sept. 2, 1915...	0 38	P.	2.69	.751	.150	1.0	.005	S.
Dec. 31, 1915...	—0 7	P.	+3.89	—0.931	+0.155	.9	—0.002	S.

Normal Equations:

$$+ 10.900\,c + 2.249\,\mu + 2.505\,\pi = + 1.425.$$
$$+ 133.027 + 14.570 = + 1.459.$$
$$+ 6.624 = + 0.482.$$

Solution:

$$c = + 0''.128.$$
$$\mu = + 0''.038 \pm 0''.003.$$
$$\pi = + 0''.032 \pm 0''.013.$$

p. e. unit weight, ± 0".028.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	+222.8	+63.6	+0.199	0.61	+37°.179
5	90.6	—53.3	.349	0.36	
7	— 54.4	+58.2	.154	0.77	+37°.174
9	259.0	—68.6	.301	0.74	+37°.168
π	10.5	17.4		1.01	+37°.175

No. 3. B.D. + 46°.243. OΣ 21. (0ʰ 57ᵐ.3; + 46° 50'.)
Mag. 6.36. $\mu = + 0''.068$ in 104°.5. Spectrum F.

This is a close double star, which is, apparently, in rapid orbital motion. The measures are in longitude. No parallax of this star has been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas-ured by.
Dec. 15, 1915...	+0 2	P.	−3.37	−0.736	+0.083	.7	+0.001	Be.
Dec. 22, 1915...	−0 5	P.	3.30	.811	.078	.8	.006	Be.
Aug. 19, 1916...	−0 37	P.	−0.89	+0.934	.103	1.0	−0.008	Be.
Aug. 25, 1916...	+0 5	Ma.	0.83	.889	.092	.8	+0.003	Sm.
Sept. 11, 1916...	−0 36	P.	0.66	.714	.095	1.0	.000	Be.
Dec. 17, 1916...	−0 6	M.	+0.31	−0.767	.104	.9	−0.008	Be.
Dec. 23, 1916...	0 2	Ma.	0.37	.828	.100	1.0	.004	Sm.
Jan. 6, 1917...	0 3	Ma.	0.51	.933	.091	.9	+0.005	Be.
Aug. 4, 1917...	−0 24	M.	+2.61	+1.004	.099	.8	+0.007	Sm.
Aug. 5, 1917...	1 34	P.	2.62	1.002	.102	.9	.004	Sm.
Aug. 10, 1917...	0 45	Ma.	2.67	0.985	.108	1.0	−0.002	Sm.

Normal Equations:

$$+ 9.8000\,c + 1.0110\,\mu + 1.5272\,\pi = + 0.9466.$$
$$+ 37.6547 + 8.1249 = + 0.2262.$$
$$+ 7.5985 = + 0.1830.$$

Solutions:

$$c = + 0''.096.$$
$$\mu = + 0''.015 \pm 0''.003.$$
$$\pi = + 0''.007 \pm 0''.008.$$

p. e. unit weight, $\pm 0''.018$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
5	+ 63.4	−262.3	+0.283	0.47	
8	203.5	11.2	.246	0.55	+46°.249
15	−244.6	+ 90.6	.249	0.56	+46°.231
18	31.9	246.0	.222	0.68	
π	0.0	0.0		0.56	+46°.243

No. 4.   B.D. + 54°.236.   Θ Cassiopeia.   (1^h 5^m.0; + 54° 37'.)
Mag. 4.52. $\mu = + 0^s.0264; - 0''.018$.   Spectrum A$_5$.

The measures were in longitude. This is a first type star with large proper motion. Jacoby gives a parallax of $0''.234 \pm 0''.067$ for this star.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Nov. 30, 1912...	—0 59	B.	—8.76	—0.431	—0.014	1.0	0.000	S.
Dec. 24, 1912...	0 21	B.	8.52	.755	.013	.7	—0.002	S.
Aug. 14, 1915...	—0 2	P.	+1.11	+1.000	—0.055	.9	+0.001	S.
Aug. 17, 1915...	0 22	P.	1.14	0.991	.051	.9	—0.004	S.
Aug. 18, 1915...	0 18	P.	1.15	.987	.052	.7	.003	S.
Aug. 23, 1915...	+0 20	P.	1.20	.964	.055	.8	.000	S.
Aug. 25, 1915...	—0 14	P.	1.22	.952	.051	.8	.004	S.
Sept. 2, 1915...	0 4	P.	1.30	.896	.059	.8	+0.004	S.
Dec. 30, 1915...	+0 7	S.	+2.49	—0.811	—0.061	.8	+0.002	S.
Dec. 31, 1915...	0 12	P.	2.50	.822	.060	.8	.001	S.
Jan. 4, 1916...	0 16	M.	2.54	.858	.056	.6	—0.002	S.
Jan. 7, 1916...	0 6	S.	2.57	.882	.054	.7	.004	S.

Normal Equations:

$$9.500\,c - 1.603\,\mu + 1.334\,\pi = -0.456.$$
$$+ 152.905 + 7.726 = -0.539.$$
$$+ 7.214 = -0.100.$$

Solution:

$$c = -0''.049.$$
$$\mu = -0''.019 \pm 0''.001.$$
$$\pi = -0''.003 \pm 0''.003.$$

p. e. unit weight, $\pm 0''.009$.

Comparison Stars.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	—152.8	+ 28.5	+0.751	0.38	
3	55.5	71.7	—0.235	0.27	
5	+ 45.3	6.9	.065	0.23	
7	163.0	—107.1	+0.549	0.24	
π	— 15.2	54.7		0.38	+54°.236

No. 5.   B.D. + 49°.444.   φ Persei.   (1^h 37^m.4; + 50° 11'.)
Mag. 4.19. $\mu = + 0^s.0029; - 0''.018$.   Spectrum Bp.

This star is a spectroscopic binary. The measures are in right ascension. No parallax of this star has been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Nov. 17, 1915...	—0 20	P.	—3.30	—0.43	—0.054	1.0	+0.009	Be.
Nov. 26, 1915...	+0 8	P.	3.21	.56	.041	.9	—0.005	Be.
Nov. 28, 1915...	—0 27	S.	3.19	.58	.040	.8	.006	Sm.
Aug. 19, 1916...	—0 38	P.	—0.54	+0.81	.043	.9	—0.006	Be.
Sept. 9, 1916...	0 23	P.	0.33	.58	.052	.9	+0.002	Be.
Sept. 11, 1916...	0 28	P.	0.31	.57	.055	.6	.004	Sm.
Dec. 10, 1916...	+0 12	M.	+0.59	—0.72	.061	.8	+0.001	Be.
Dec. 14, 1916...	—0 26	M.	0.63	.77	.063	.8	.003	Be.
Dec. 16, 1916...	+0 9	Ma.	0.65	.78	.052	.5	—0.008	Sm.
Aug. 5, 1917...	—1 32	P.	+2.97	+0.91	.065	.6	+0.004	Sm.
Aug. 12, 1917...	1 1	P.	3.04	.87	.062	1.0	.001	Sm.
Aug. 13, 1917...	1 13	P.	3.05	.86	.058	1.0	—0.003	Sm.

Normal Equations:

$$+ 9.8000\,c - 0.5370\,\mu + 0.8890\,\pi = -0.5256.$$
$$+ 53.3666 + 9.7531 = -0.1134.$$
$$+ 5.0110 = -0.0599.$$

Solution:

$$c = -0''.054.$$
$$\mu = -0''.016 \pm 0''.003.$$
$$\pi = +0''.021 \pm 0''.010.$$

p. e. unit weight, $\pm 0''.017$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—191.9	+200.8	+0.214	0.52	+50°.330
6	+ 70.2	77.7	.221	0.44	
10	192.2	22.8	.224	0.49	+49°.450
14	85.8	—220.3	.180	0.49	+49°.446
20	—204.1	160.2	.161	0.24	+49°.437
π	0.0	0.0		0.53	+49°.444

No. 6.   B.D. + 1°.347.   Σ 186.   (1ʰ 50ᵐ.7; + 1° 21'.)
Mag. 6.18. $\mu = + 0^s.0105; + 0''.182$.   Spectrum F.

This is a binary of long period. The combined image of the two components was bisected in making the measures. The image is sensibly round. The measures are in longitude. Russell publishes a hypothetical parallax of 0''.025 for this star.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Dec. 26, 1915...	+0 46	M.	—2.80	—0.912	—0.027	.9	—0.001	Sm.
Dec. 31, 1915...	0 5	P.	2.75	.940	.024	.5	.004	Sm.
Jan. 4, 1916...	0 21	M.	2.71	.982	.033	.6	+0.005	Be.
Aug. 13, 1916...	—0 46	P.	—0.49	+ .917	+0.014	.6	+0.001	Be.
Sept. 3, 1916...	+0 42	M.	0.28	.709	.014	1.0	.002	Be.
Sept. 16, 1916...	0 34	M.	0.15	.532	.023	.5	—0.007	Sm
Dec. 10, 1916...	+0 52	M.	+0.70	— .781	+0.011	.9	+0.003	Be.
Dec. 19, 1916...	0 58	M.	+0.79	.865	.022	.5	—0.007	Sm
Jan. 16, 1917...	—0 22	M.	+1.07	.984	.016	1.0	+0.001	Be.
Aug. 25, 1917...	—0 42	M.	+3.28	+ .812	+0.064	1.0	—0.005	Sm.
Aug. 27, 1917...	0 18	P.	3.30	.792	.054	1.0	+0.005	Sm

Normal Equations:

$$+ 8.5000\,c + 2.5050\,\mu - 0.8702\,\pi = + 0.1327.$$
$$+ 39.0238 \quad + 8.0698 \quad\quad = + 0.5658.$$
$$+ 6.0956 \quad\quad = + 0.1384.$$

Solution:

$$c = + 0''.013.$$
$$\mu = + 0''.055 \pm 0''.003.$$
$$\pi = + 0''.042 \pm 0''.006.$$

p. e. unit weight, $\pm 0''.013$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—190.6	—183.9	+0.328	0.52	+0°.308
4	+210.5	150.4	.144	0.47	+0°.314
7	11.7	+221.7	.307	0.61	+1°.348
8	129.8	62.3	.221	0.41	+1°.350
π	0.0	0.0		0.82	+1°.347

No. 7. B.D. + 41°.395. γ^1 (A) and γ^2 (BC) Andromedae.
(1^h 57^m.8; + 41° 51'.) Mag. 2.28 — 5.08.

$$\mu = \left\{ \begin{array}{cc} + 0^s.0042; & - 0''.052. \\ 1 & 1. \end{array} \right. \quad \text{Spectrum } K_p.$$

The measures are in longitude. BC is a binary with a period of about 55 years. Flint found the parallax of γ^1 to be —0''.015 ± 0''.027, Chase, 0''.000 ± 0''.009, Russell (Hypothetical), + 0''.015. The same comparison field is used for γ^1 and for γ^2.

TABLE AND SOLUTIONS FOR γ^1 (A) ANDROMEDAE.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Aug. 13, 1916...	—0 20	P.	—2.20	+1.002	+0.192	.8	—0.004	P.
Aug. 17, 1916...	0 0	P.	2.16	0.990	.200	.9	.012	P.
Sept. 17, 1916...	0 45	P.	1.85	.746	.190	.9	.002	P.
Sept. 17, 1916...	0 22	P.	1.85	.746	.176	.9	+0.012	P.
Sept. 20, 1916...	0 0	Ma.	1.82	.709	.170	1.0	.018	P.
Dec. 19, 1916...	0 0	M.	—0.92	—0.692	.194	.7	—0.008	P.
Jan. 2, 1917...	+0 6	M.	0.78	.843	.196	1.0	.010	P.
Jan. 6, 1917...	—0 8	Ma.	0.74	.876	.176	.6	+0.010	P.
Jan. 8, 1917...	0 22	P.	0.72	.892	.188	.7	—0.002	P.
Aug. 5, 1917...	—1 8	P.	+1.37	+1.014	.179	.5	+0.024	P.
Aug. 12, 1917...	0 46	P.	1.44	1.005	.226	.8	—0.023	P.
Aug. 26, 1917...	0 57	P.	1.58	0.946	.206	.9	.002	P.
Dec. 30, 1917...	+0 4	M.	+2.84	—0.812	.200	1.0	+0.001	P.
Jan. 5, 1918...	—0 12	Ma.	2.90	.866	.207	.5	—0.006	P.
Jan. 13, 1918...	+0 1	M.	2.98	.924	.190	.8	+0.011	P.

Normal Equations:

$$+ 12.0000\,c - 1.2930\,\mu + 1.4452\,\pi = + 2.3132.$$
$$+ 43.6553 - 8.0880 = - 0.0992.$$
$$+ 9.0978 = + 0.2846.$$

Solution:

$$c = + 0''.193.$$
$$\mu = + 0''.020 \pm 0''.006.$$
$$\pi = + 0''.021 \pm 0''.014.$$

p. e. unit weight, ± 0''.037.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	− 71.6	−141.0	+0.259	0.56	
6	+ 75.3	+183.1	.249	0.64	+41°.399
10	163.6	−110.1	.056	0.44	
12	− 92.9	36.3	.319	0.41	
14	+175.8	+ 74.6	.117	0.42	
γ^1	0.0	0.0		1.01	+41°.395

TABLE AND SOLUTIONS FOR γ^2 (B) ANDROMEDAE.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Aug. 13, 1916...	−0 20	P.	−2.11	+1.002	−0.048	1.0	−0.007	P.
Aug. 17, 1916...	0 0	P.	2.07	0.990	.052	.9	.003	P.
Sept. 17, 1916...	0 45	P.	1.76	.746	.053	.5	.001	P.
Sept. 17, 1916...	0 22	P.	1.76	.746	.066	.9	+0.012	P.
Sept. 20, 1916...	0 0	Ma.	1.73	.709	.066	.8	.012	P.
Dec. 19, 1916...	0 0	M.	0.83	−0.692	.054	.8	0.000	P.
Jan. 2, 1917...	+0 6	M.	0.69	.843	.046	.7	−0.008	P.
Jan. 6, 1917...	−0 8	Ma.	0.65	.876	.050	.8	.004	P.
Jan. 8, 1917...	0 22	P.	0.63	.892	.054	.7	0.000	P.
Aug. 12, 1917...	−0 46	P.	+1.53	+1.005	.044	.9	−0.003	P.
Aug. 26, 1917...	0 57	P.	1.67	0.946	.041	.7	.006	P.
Dec. 30, 1917...	+0 4	M.	2.93	−0.812	.055	.8	+0.009	P.
Jan. 5, 1918...	−0 12	Ma.	2.99	.866	.042	.5	−0.004	P.
Jan. 13, 1918...	+0 1	M.	3.07	.924	.047	.8	+0.001	P.

Normal Equations:

$$+ 10.8000\,c - 1.0880\,\mu + 0.7806\,\pi = -0.5576.$$
$$+ 39.4766 - 8.0400 = + 0.1329.$$
$$+ 8.2397 = -0.0484.$$

Solution:

$$c = -0''.051.$$
$$\mu = + 0''.010 \pm 0''.004.$$
$$\pi = + 0''.005 \pm 0''.008.$$

p. e. unit weight, $\pm$ 0''.021.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	— 71.6	—141.0	+0.255	0.56	
6	+ 75.3	+183.1	.251	0.64	+41°.399
10	163.6	—110.1	.059	0.44	
12	— 92.9	36.3	.314	0.41	
14	+175.8	+ 74.6	.121	0.42	
γ^2	2.9	1.0		0.47	

No. 8. B.D. + 67°.191. Bradley 3227. (2^h $7^m.5$; + 67° 13'.) Mag. 7.8. $\mu = + 0^s.0902$; — 0".299. Spectrum K.

The measures of this star were made in longitude. Smith-Elkin found (Heliometer) a parallax for this star of + 0".09 ± 0".041. Adams found a parallax for it (Spectroscopic) of + 0".044.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution. m.	Wt., p.	Res., v.	Meas-ured by.
Sept. 10, 1915...	+0 27	Ma.	—4.33	+0.957	—0.193	.9	—0.004	Be.
Sept. 13, 1915...	—0 16	P.	4.30	.939	.198	1.0	+0.002	Be.
Sept. 15, 1915...	0 52	P.	4.28	· .925	.195	.9	—0.001	Be.
Sept. 16, 1915...	0 2	M.	4.27	.918	.208	1.0	+0.012	Be.
Dec. 30, 1915...	—0 10	S.	—3.22	—0.615	.184	1.0	—0.008	Be.
Sept. 17, 1916...	+0 10	P.	—0.60	+0.905	.112	.6	—0.011	Be.
Oct. 7, 1916...	0 34	M.	0.40	.701	.126	.5	+0.005	Bc.
Oct. 10, 1916...	—0 14	P.	0.37	.663	.124	.9	.003	Be.
Jan. 8, 1917...	+0 4	P.	+0.53	—0.739	.116	.7	—0.002	Be.
Jan. 12, 1917...	—0 8	P.	0.57	.782	.128	1.0	+0.010	Be.
Jan. 12, 1917...	+0 19	P.	0.57	.782	.103	.8	—0.015	Be.
Jan. 16, 1917...	0 12	M.	0.61	.824	.106	.5	.012	Be.
Jan. 30, 1917...	0 36	P.	0.75	.932	.126	1.0	+0.010	Be.
Sept. 12, 1917...	+0 2	Ma.	+3.00	+0.942	.044	.7	—0.006	Sm.
Sept. 19, 1917...	0 22	Ma.	3.07	.892	.047	.5	.003	Sm.
Jan. 5, 1918...	+0 13	Ma.	+4.15	—0.700	.059	.9	+0.013	Sm.
Jan. 10, 1918...	0 2	M.	4.20	.759	.046	.9	.001	Sm.
Jan. 20, 1918...	—0 1	M.	4.30	.859	.037	.9	— .007	Sm.

Normal Equations:

$$+ 14.7000\,c - 2.9600\,\mu + 0.1763\,\pi = - 1.8337.$$
$$+ 141.4308 - 21.4438 = + 2.9503.$$
$$+ 10.1634 = - 0.3384.$$

Solution: $c = -0''.121.$

$\mu = + 0''.094 \pm 0''.003.$

$\pi = + 0''.052 \pm 0''.010.$

p. e. unit weigth, $\pm 0''.026.$

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	−239.9	+253.7	+0.185	0.62	+67°.187
6	+205.0	37.8	.202	0.48	
12	5.6	−163.1	.486	0.81	+66°.192
15	19.8	+193.4	.127	0.50	
π	0.0	0.0		0.77	+67°.191

No. 9. B.D. + 24°.375–6. Bradley 360–1. (2ʰ 31ᵐ.2 ; + 24° 12'.8.)

Mag. 7.3–6.9 $\mu = \begin{cases} + 0^s.0111 ; - 0''.009. \\ + 0^s.0102 ; - 0''.010. \end{cases}$ Spectrum F, F₅.

The measures are in longitude. The components have a common proper motion. Other published parallaxes are

Von Maanen, (photographic), + 0''.008 ± 0''.015, (360).

+ 0''.028 ± 0''.014, (361).

Adams,   (spectroscopic), + 0''.018,   (360).

+ 0''.028,   (361).

The same comparison field was used for both components.

TABLE AND SOLUTIONS FOR BRADLEY 361.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 19, 1915...	−0 34	M.	−2.28	+0.735	−0.093	.8	0.000	Be.
Sept. 21, 1915...	0 34	P.	2.26	.710	.086	.7	−0.007	Be.
Sept. 23, 1915...	0 30	P.	2.24	.684	.098	.8	+0.005	Be.
Dec. 21, 1915...	+1 10	M.	−1.35	−0.704	.096	.5	0.000	Sm.
Dec. 26, 1915...	1 21	M.	1.30	.762	.104	.9	+0.007	Be.
Dec. 30, 1915...	0 9	S.	1.26	.803	.092	.8	−0.005	Sm.
Feb. 3, 1916...	1 21	M.	0.91	.986	.094	.8	.002	Be.
Sept. 9, 1916...	+0 10	P.	+1.28	+0.835	.068	.8	−0.003	Be.
Sept. 13, 1916...	0 16	Ma.	1.32	.794	.073	1.0	+0.002	Be.
Sept. 16, 1916...	0 54	M.	1.35	.760	.074	.5	.003	Sm.
Dec. 31, 1916...	+0 59	M.	+2.41	−0.821	.072	1.0	−0.003	Sm.
Jan. 19, 1917...	−0 3	P.	2.60	.955	.078	.9	+0.003	Be.
Jan. 20, 1917...	0 16	Ma.	2.61	.959	.074	.9	−0.001	Sm.

Normal Equations:

$$+ 10.4000\,c + 1.3390\,\mu - 1.5384\,\pi = -0.8766.$$
$$+ 38.1003 - 4.8455 = +0.0831.$$
$$+ 7.0229 = +0.1458.$$

Solution:

$$c = -0''.084.$$
$$\mu = +0''.028 \pm 0''.002.$$
$$\pi = +0''.030 \pm 0''.005.$$

p. e. unit weight, $\pm 0''.012.$

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	− 47.6	−166.9	+0.005	0.64	
4	289.0	31.5	.373	0.60	
8	+145.6	49.3	.205	0.42	
10	188.0	+ 53.4	.417	0.30	
Br. 361	0.0	0.0		1.10	+24°.376

TABLE AND SOLUTIONS FOR BRADLEY 360.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 19, 1915...	−0 34	M.	−2.29	+0.735	−0.056	.8	+0.001	Be.
Sept. 21, 1915...	0 34	P.	2.27	.710	.056	.5	.001	Be.
Sept. 23, 1915...	0 30	P.	2.25	.684	.051	.8	−0.004	Be.
Dec. 21, 1915...	+1 10	M.	−1.36	−0.704	.062	.9	+0.002	Sm.
Dec. 26, 1915...	1 21	M.	1.31	.762	.064	.8	.004	Be.
Dec. 30, 1915...	0 9	S.	1.27	.803	.054	1.0	−0.006	Sm.
Feb. 3, 1916...	1 21	M.	0.92	.986	.062	.5	+0.003	Be.
Sept. 9, 1916...	+0 10	P.	+1.27	+0.835	.038	.9	+0.005	Be.
Sept. 13, 1916...	0 16	Ma.	1.31	.794	.029	.8	−0.004	Be.
Sept. 16, 1916...	0 54	M.	1.34	.760	.032	1.0	.001	Sm.
Jan. 16, 1917...	+0 57	M.	+2.56	−0.940	.038	.5	0.000	Sm.
Jan. 19, 1917...	−0 3	P.	2.59	.955	.035	.8	−0.003	Be.
Jan. 20, 1917...	0 16	Ma.	2.60	.959	.040	.5	+0.002	Sm.

Normal Equations:

$$+ 9.8000\,c - 0.5860\,\mu - 0.6158\,\pi = -0.4620.$$
$$+ 32.5387 - 1.8737 = +0.2081.$$
$$+ 6.4407 = +0.0640.$$

Solution:

$$c = -0''.046.$$

$$\mu = +0''.028 \pm 0''.002.$$

$$\pi = +0''.034 \pm 0''.004.$$

p. e. unit weight, $\pm 0''.011$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	— 47.6	—166.9	—0.001	0.64	
4	289.0	31.5	+0.394	0.60	
8	+145.6	49.3	.195	0.42	
10	188.0	+ 53.4	.412	0.40	
Br. 360	— 8.1	0.7		0.95	+24°.375

No. 10. B.D. + 49°.857. ι Persei. (3ʰ 2ᵐ.0; + 49° 14'.)
Mag. 4.17. $\mu = +0^s.1292$; — 0''.080. Spectrum G.

The measures are in longitude. This star has a radial velocity of 50.5 km. per second. Other published parallaxes are

Flint $+0''.10 \pm 0''.033$, (Transits).

Chase $+0''.11 \pm 0''.027$, (Heliometer).

Adams $0''.096$,   (Spectroscopic).

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Jan. 1, 1914...	—0 7	P.	—3.08	—0.668	—0.231	.7	+0.004	S.
Jan. 6, 1914...	0 10	P.	3.03	.730	.228	1.0	.003	S.
Jan. 14, 1914...	+0 6	P.	2.95	.816	.214	.8	—0.008	S.
Sept. 8, 1914...	—0 14	P.	—0.58	+0.958	.018	.7	+0.003	S.
Sept. 21, 1914...	0 1	P.	0.45	.864	.009	1.0	.000	S.
Sept. 22, 1914...	+0 2	P.	0.44	.855	.002	.7	—0.006	S.
Jan. 1, 1915...	—0 4	P.	+0.57	—0.664	+.011	.7	+0.011	S.
Jan. 4, 1915...	+0 3	P.	0.60	.702	.043	.5	—0.020	S.
Jan. 5, 1915...	0 12	M.	0.61	.714	.017	.7	+0.007	S.
Aug. 22, 1915...	—0 42	P.	+2.90	+1.011	.225	1.0	—0.001	S.
Aug. 23, 1915...	0 42	P.	2.91	1,010	.230	.9	.006	S.
Aug. 25, 1915...	0 48	P.	2.93	1.008	.218	.8	+0.008	S.

Normal Equations:

$$+9.500\,c + 0.279\,\mu + 1.693\,\pi = +0.064.$$
$$+46.923 + 11.695 = +3.496.$$
$$+ 6.944 = +0.975.$$

Solution:

$$c = +0''.000.$$
$$\mu = +0''.319 \pm 0''.005.$$
$$\pi = +0''.120 \pm 0''.012.$$

p. e. unit weight, $\pm 0''.024$.

<div align="center">COMPARISON STARS.</div>

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	−213.0	−160.2	+0.355	0.58	
2	7.2	+ 30.0	.376	0.52	
3	+120.0	10.6	−0.083	0.71	
6	+100.3	119.6	+0.352	0.50	
π	− 53.0	− 4.4		0.63	$+49°.857$

No. 11.   B.D. $+0°.542$. Σ 367.   ($3^h\ 9^m.0$; $+0°\ 21'.7$.)
Mag. 8.0–8.0.

The measures are in longitude. The components are separated by $0''.95$. The combined image of the components if not round is very slightly elongated. We attempted to bisect the combined image. No other parallaxes of this star have been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 9, 1915...	−0 16	P.	−2.79	+0.857	−0.138	.8	−0.006	Be.
Sept. 16, 1915...	+0 32	M.	2.72	.786	.146	.5	+0.002	Be.
Sept. 23, 1915...	−0 13	P.	2.65	.705	.153	.9	.008	Be.
Jan. 23, 1916...	+0 12	S.	−1.43	−0.962	.149	.9	−0.003	Be.
Jan. 24, 1916...	0 28	P.	1.42	.965	.152	1.0	.000	Be.
Sept. 20, 1916...	−0 16	Ma.	+0.98	+0.732	.140	.9	+0.001	Be.
Sept. 25, 1916...	0 6	M.	1.03	.669	.132	.5	−0.008	Be.
Jan. 6, 1917...	+0 12	Ma.	+2.06	−0.861	.147	1.0	0.000	Be.
Jan. 20, 1917...	−0 5	Ma.	2.20	.953	.140	.6	−0.007	Sm. Be.
Jan. 28, 1917...	+0 50	M.	2.28	.979	.148	.6	+0.001	Sm. Be.
Feb. 14, 1917...	1 15	P.	2.45	.971	.158	.5	.011	Be.

Normal Equations:

$$+ 8.2000\,c - 1.3140\,\mu - 1.6301\,\pi = -1.1980.$$
$$+ 34.7662 - 6.6250 = + 0.2040.$$
$$+ 6.1467 = + 0.2605.$$

Solution:

$$c = -0''.145.$$
$$\mu = + 0''.007 \pm 0''.003.$$
$$\pi = + 0''.026 \pm 0''.008.$$

p. e. unit weight, $\pm 0''.017.$

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	—221.2	—156.8	+0.402	0.70	
5	+180.8	+124.4	.349	0.88	+0°.547
6	150.8	97.6	.284	0.49	+0°.546
9	143.6	— 49.2	—0.035	0.55	+0°.545
π	0	0		0.97	+0°.542

No. 12. B.D. + 31°.642. o Persei = β 535. (3^h 38^m; + 31° 58'.)
Mags. 4.0-8.5. $\mu = + 0^s.0008$; — 0''.024. Spectrum B$_1$.

The measures are in longitude. The components of this star are separated by 0''.83. The combined image of the components seemed round. No other parallaxes have been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Oct. 7, 1916...	+0 3	M.	—2.64	+0.704	+0.094	1.0	0.000	Sm.
Oct. 10, 1916...	—0 6	P.	2.61	.666	.090	.9	+0.004	Sm.
Dec. 31, 1916...	+0 41	M.	—1.79	—0.636	.092	1.0	—0.005	Sm.
Jan. 12, 1917...	0 23	P.	1.67	.780	.080	.5	+0.006	Sm.
Jan. 30, 1917...	0 23	M.	1.49	.931	.087	.9	—0.002	Sm.
Sept. 19, 1917...	+0 26	Ma.	+0.83	+0.893	.103	.5	—0.005	Sm.
Oct. 2, 1917...	—0 25	P.	0.96	.766	.094	.7	+0.003	Sm.
Oct. 6, 1917...	0 12	M.	1.00	.719	.091	.9	.006	Sm.
Oct. 6, 1917...	+0 26	M.	1.00	.719	.106	1.0	—0.009	Sm.
Jan. 1, 1918...	+1 16	M.	+1.87	—0.646	.088	1.0	+0.001	Sm.
Feb. 7, 1918...	1 10	M.	2.24	.968	.086	1.0	.001	Sm.
Feb. 13, 1918...	0 14	M.	2.30	.984	.086	1.0	.001	Sm.

Normal Equations:

$$+ 10.4000\,c + 0.4420\,\mu - 0.8097\,\pi = + 0.9505.$$
$$+ 36.3912 \quad -3.7729 \quad = + 0.0411.$$
$$+ 6.4979 \quad = - 0.0357.$$

Solution: $c = + 0''.092.$

$$\mu = + 0''.003 \pm 0''.003.$$
$$\pi = + 0''.030 \pm 0''.006.$$

p. e. unit weight, $\pm 0''.015$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	+193.6	+117.6	+0.282	0.88	+31°.645
4	44.4	— 91.6	.253	0.56	
8	— 26.0	129.2	.243	0.68	
10	289.2	+ 75.2	.222	0.49	
π	0	0		0.89	+31°.642

No. 13.   B.D. + 34°.796.   Greenwich$_{60}$ 284 = Lalande 7443.
($3^h\ 56^m.5$; + 35° 2'.)   Mag. 8.5. $\mu = 0^s.1420$; — $1''.354$.

The measures are in longitude.   Other parallaxes published are:

Russell   — $0''.011 \pm 0''.014$, (Photographic).

Schlesinger + $0''.039 \pm 0''.013$, (Photographic).

Flint   — $0''.020 \pm 0''.055$, (Transits).

Chase   + $0''.04\ \pm 0''.026$, (Heliometer).

Adams   + $0''.042$,   (Spectroscopic).

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Sept. 21, 1914...	—0 6	P.	—1.75	+0.915	+0.016	1.0	—0.003	S.
Sept. 22, 1914...	0 9	P.	1.74	.908	.016	.7	.003	S.
Sept. 27, 1914...	0 7	S.	1.69	.869	.019	.9	.002	S.
Sept. 28, 1914...	0 14	P.	1.68	.859	.016	.8	+0.001	S.
Oct. 1, 1914...	0 40	P.	1.65	.830	.018	.9	.002	S.
Jan. 1, 1915...	—0 8	P.	—0.73	—0.578	.069	.9	+0.005	S.
Jan. 5, 1915...	+0 7	M.	0.69	.633	.074	1.0	.003	S.
Jan. 8, 1915...	—0 6	P.	0.66	.673	.082	.7	—0.003	S.
Sept. 9, 1915...	+0 7	P.	+1.78	+0.984	.309	.8	—0.002	S.
Sept. 24, 1915...	—0 43	Ma.	1.93	.896	.311	.9	+0.007	S.
Feb. 19, 1916...	+0 52	Ma.	+3.41	—0.985	.416	.8	—0.004	S.
Feb. 21, 1916...	0 55	P.	3.43	.988	.415	.7	.001	S.

Normal Equations:

$$+ 10.100\,c - 0.837\,\mu + 2.257\,\pi = + 1.417.$$
$$+ 37.146 \quad -7.390 \quad = + 2.853.$$
$$+ 7.279 \quad = -0.178.$$

Solution:

$$c = + 0''.144.$$
$$\mu = + 0''.390 \pm 0''.002.$$
$$\pi = + 0''.072 \pm 0''.005.$$

p. e. unit weight, $\pm$ 0''.012.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—161.7	—89.5	+0.264	0.63	
3	164.8	+55.2	.247	0.48	
5	+137.3	64.2	.240	0.45	
6	189.1	—30.0	.249	0.52	
π	— 3.3	2.0		0.76	+34°.796

No. 14.   B.D. + 53°.794. Σ 566.   (4^h 32^m.0; + 53° 16'.6.).

Mag. 5.44. $\mu = + 0^s.0075$; — 0''.090.   Spectrum A.

This is a triple star. The distance between AB is 0''.21 and between AB and C is 1''.58. The combined image of these three stars was elongated. We attempted to measure to the center of gravity of this elongated image. The measures are in longitude. No other parallaxes of this star have been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Feb. 21, 1915...	+0 8	M.	—6.91	—0.964	+0.096	1.0	—0.004	Sm.
Sept. 27, 1915...	—0 36	S.	—4.73	+0.947	.101	1.0	+0.004	Sm.
Oct. 9, 1915...	0 40	M.	4.61	.856	.107	1.0	—0.003	Sm.
Jan. 23, 1916...	—0 34	S.	—3.55	—0.727	.089	.8	+0.010	Sm.
Sept. 17, 1916...	—0 30	P.	—1.17	+0.989	.122	.7	—0.011	Sm.
Sept. 20, 1916...	0 0	Ma.	1.14	.978	.106	.8	+ .005	Sm.
Jan. 2, 1917...	—0 23	M.	—0.10	—0.447	.098	1.0	+0.008	Sm.
Jan. 6, 1917...	0 18	Ma.	0.06	.507	.096	.5	.010	Sm.
Jan. 28, 1917...	+0 2	M.	+0.16	.791	.121	1.0	—0.016	Sm.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Sept. 19, 1917...	0 0	Ma.	+2.50	+0.983	.124	.5	—0.007	Sm.
Oct. 2, 1917...	—0 30	P.	2.63	.910	.114	.8	+0.003	Sm.
Oct. 2, 1917...	0 0	P.	2.63	.910	.119	.5	—0.002	Sm.
Oct. 6, 1917...	+0 7	M.	2.67	.878	.114	1.0	+0.003	Sm.
Jan. 21, 1918...	+0 5	M.	+3.74	—0.709	.114	1.0	—0.003	Sm.
Feb. 8, 1918...	—0 41	P.	3.92	.890	.108	.5	+0.003	Sm.
Feb. 11, 1918...	0 34	P.	3.95	.912	.108	.9	.003	Sm.

Normal Equations:

$$+ 13.0000\,c - 4.1970\,\mu + 0.8183\,\pi = + 1.4043.$$
$$+ 158.4493 - 2.4220 = - 0.1993.$$
$$+ 9.3634 = + 0.1271.$$

Solution:

$$c = + 0''.108.$$
$$\mu = + 0''.008 \pm 0''.002.$$
$$\pi = + 0''.021 \pm 0''.007.$$

p. e. unit weight, $\pm 0''.023$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+135.6	—159.2	+0.242	0.58	+52°.869
3	— 59.2	193.2	.217	0.60	+52°.862
10	+156.4	+ 79.2	.280	.042	
15	—244.0	223.2	.261	0.59	+53°.789
π	0.0	0.0		0.68	+53°.794

No. 15. B.D. + 53°.3796 = Δ 4. (4ʰ 32ᵐ.5; + 53° 17'.)
Mag. 8.8–9.8.

No parallaxes of this star have been published. The same plates and same set of comparison stars were used to derive the parallax of Σ 566 and that of Δ 4. We have designated the brighter component of Δ 4 by Δ 4 and the fainter component by Δ 4'.

TABLE AND SOLUTIONS FOR $\Delta 4$.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Feb. 21, 1915...	+0 8	M.	—6.91	—0.964	+0.024	.5	—0.005	Sm.
Sept. 27, 1915...	—0 36	S.	—4.73	+0.947	.022	9	+0.003	Sm.
Oct. 9, 1915...	0 40	M.	4.61	.856	.033	.7	—0.008	Sm.
Jan. 23, 1916...	—0 34	S.	—3.55	—0.727	.019	1.0	+0.006	Sm.
Sept. 17, 1916...	—0 30	P.	—1.17	+0.989	.038	.5	—0.007	Sm.
Sept. 20, 1916...	0 0	Ma.	1.14	.978	.031	1.0	0.000	Sm.
Jan. 2, 1917...	—0 23	M.	—0.10	—0.447	.024	.6	+0.008	Sm.
Jan. 6, 1917...	0 18	Ma.	0.06	.507	.023	.5	.009	Sm.
Jan. 28, 1917...	+0 2	M.	+0.16	.791	.039	.9	—0.007	Sm.
Sept. 19, 1917...	0 0	Ma.	+2.50	+0.983	.024	.5	+0.014	Sm.
Oct. 2, 1917...	—0 30	P.	2.63	.910	.044	1.0	—0.006	Sm.
Oct. 2, 1917...	0 0	P.	2.63	.910	.045	.5	.007	Sm.
Oct. 6, 1917...	+0 7	M.	2.67	.878	.026	.5	+0.012	Sm.
Jan. 21, 1918...	+0 5	M.	+3.74	—0.709	.042	.5	—0.004	Sm.
Feb. 8, 1918...	—0 41	P.	3.92	.890	.037	.5	+0.002	Sm.
Feb. 11, 1918...	—0 34	P.	3.95	.912	.042	1.0	—0.003	Sm.

Normal Equations:

$$+ 11.1000\,c — 1.8500\,\mu + 1.0654\,\pi = + 0.3579.$$
$$+ 120.8478 — 3.3294 = + 0.1520.$$
$$+ 8.1602 = + 0.0363.$$

Solution:

$$c = + 0''.032.$$
$$\mu = + 0''.008 \pm 0''.002.$$
$$\pi = + 0''.004 \pm 0''.007.$$

p. e. unit weight, $\pm 0''.020.$

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+135.6	—159.2	+0.288	0.58	+52°.869
3	— 59.2	193.2	.140	0.60	+52°.862
10	+156.4	+ 79.2	.397	0.42	
15	—244.0	223.2	.175	0.59	+53°.789
π	+ 50.0	— 2.7		0.73	+53°.796

TABLE AND SOLUTIONS FOR $\Delta 4'$.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Feb. 21, 1915...	+0 8	M.	—6.91	—0.964	+0.034	1.0	+0.010	Sm.
Sept. 27, 1915...	—0 36	S.	—4.73	+0.947	.044	.8	—0.004	Sm.
Oct. 9, 1915...	0 40	M.	4.61	.856.	.044	.8	.004	Sm.
Jan. 23, 1916...	—0 34	S.	—3.55	—0.727	.045	.6	—0.004	Sm.
Sept. 17, 1916...	—0 30	P.	—1.17	+0.989	.039	1.0	—0.001	Sm.
Sept. 20, 1916...	0 0	Ma.	1.14	.978	.036	.9	+0.002	Sm.
Jan. 2, 1917...	—0 23	M.	—0.10	—0.447	.046	1.0	—0.008	Sm.
Jan. 6, 1917...	0 18	Ma.	0.06	.507	.027	.5	+0.011	Sm.
Jan. 28, 1917...	+0 2	M.	+0.16	.791	.054	.6	—0.016	Sm.
Sept. 19, 1917...	0 0	Ma.	+2.50	+0.983	.023	.5	—0.012	Sm.
Oct. 2, 1917...	—0 30	P.	2.63	.910	.036	1.0	.001	Sm.
Oct. 2, 1917...	0 0	P.	2.63	.910	.041	.5	.006	Sm.
Oct. 6, 1917...	+0 7	M.	2.67	.878	.031	1.0	+0.004	Sm.
Jan. 21, 1918...	+0 5	M.	+3.74	—0.709	.022	1.0	+0.013	Sm.
Feb. 8, 1918...	—0 41	P.	3.92	.890	.050	.7	—0.015	Sm.
Feb. 11, 1918...	0 34	P.	3.95	.912	.031	.5	+0.004	Sm.

Normal Equations:

$$+ 12.4000\,c — 2.4180\,\mu + 1.6828\,\pi = + 0.4662.$$
$$+ 145.9499 — 0.4393 = — 0.2015.$$
$$+ 9.0619 = + 0.0573.$$

Solution:

$$c = + 0''.038.$$
$$\mu = — 0''.004 \pm 0''.002.$$
$$\pi = — 0''.003 \pm 0''.009.$$

p. e. unit weight, $\pm 0''.026$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+135.6	—59.2	+0.288	0.58	+52°.869
3	— 59.2	193.2	.142	0.60	+52°.862
10	+156.4	+ 79.2	.393	0.42	
15	—244.0	223.2	.177	0.59	+53°.789
$\Delta 4'$	+ 48.8	— 2.9		0.52	

No. 16.   B.D. + 45°.992.   Groombridge 884.   (4^h 44^m.4; + 45° 41'.)
Mag. 6.5. μ = + 0^s.0358; — 0".562.

The measures were in longitude.   Other parallaxes published are:

Russell, (Photographic),   + 0".078 ± 0".019.

Elkins-Chase, (Heliometer),   + 0".12 ± 0".025.

Adams, (Spectroscopic),   0".07.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Oct. 11, 1915...	—0 26	M.	—5.01	+0.845	—0.030	.8	+0.005	Be.
Oct. 24, 1915...	0 30	P.	4.88	.703	.030	1.0	.005	Be.
Oct. 28, 1916...	—0 36	M.	—1.18	+0.642	+0.030	.8	+0.005	Be.
Oct. 28, 1916...	+0 7	M.	1.18	.642	.045	1.0	—0.010	Be.
Nov. 7, 1916...	—0 8	P.	1.08	.498	.044	1.0	.009	Sm.
Jan. 2, 1917...	+0 7	M.	—0.52	—0.433	+ .039	1.0	—0.010	Be.
Jan. 16, 1917...	—0 24	M.	0.38	.637	.028	1.0	+0.001	Be.
Feb. 12, 1917...	+0 11	M.	0.11	.914	.018	.8	.011	Sm.
Oct. 13, 1917...	—0 19	M.	+2.32	+0.821	+ .094	.5	+0.002	Sm.
Oct. 30, 1917...	0 11	P.	2.49	.618	.096	.9	—0.001	Sm.
Oct. 31, 1917...	+0 2	Ma.	2.50	.604	.084	.8	+0.011	Sm.
Feb. 11, 1918...	—0 10	P.	+3.53	—0.906	+ .099	.5	—0.010	Sm.
Feb. 13, 1918...	0 12	P.	3.55	.919	.085	.9	+0.005	Sm.

Normal Equations:

$$+ 11.0000\, c — 2.7190\, \mu + 1.4012\, \pi = + 0.4670.$$
$$+ 78.8357 \quad —9.1612 \quad = + 1.0437.$$
$$+ 5.4600 \quad = — 0.0056.$$

Solution: c = + 0".045.

μ = + 0".078 ± 0".003.

π = + 0".072 ± 0".012.

p. e. unit weight, ± 0".025.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+181.8	— 95.2	+0.202	0.54	
3	148.0	+ 19.6	.215	0.60	
5	—104.4	235.2	.295	0.51	+45°.990
10	129.6	—189.2	.288	0.46	
π	0	0		0.76	+45°.992

No. 17. B.D. — 5°.1123. Weisse 4ʰ.1189. (4ʰ 55ᵐ.9; — 5°, 52′.)
Mag. 6.5. $\mu = + 0^s.040$; — 1″.10. Spectrum K.

The measures are in longitude. Other published parallaxes are:

Flint, (Transits),   + 0″.29 ± 0″.042.
Smith, (Heliometer),   + 0″.104 ± 0″.015.
Adams, (Spectroscopic), + 0″.12.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Jan. 30, 1913...	+0 37	M.	—3.09	—0.841	—0.092	.6	—0.003	M.
Feb. 5, 1913...	—0 18	B.	3.03	.891	.109	.6	+0.015	M.
Oct. 13, 1913...	+0 10	M.	—0.53	+0.781	+0.010	.8	+0.007	M.
Oct. 22, 1913...	0 50	S.	0.44	.674	.035	.8	—0.017	M.
Oct. 28, 1913...	0 30	P.	0.38	.593	.020	.9	.002	M.
Nov. 2, 1913...	0 20	P.	0.33	.521	.015	.9	+0.003	M.
Jan. 1, 1914...	—0 18	P.	+0.27	—0.475	+0.018	.5	—0.004	M.
Jan. 5, 1914...	0 3	P.	0.31	.535	.018	.9	.004	M.
Feb. 2, 1914...	+0 2	S.	0.59	.865	.011	.9	+0.004	M.
Feb. 21, 1914...	—0 2	M.	0.78	.976	.027	.5	—0.009	M.
Sept. 21. 1914...	—0 2	P.	+2.90	+0.962	+0.120	.9	+0.005	M.
Sept. 22, 1914...	+0 12	P.	2.91	.957	.122	1.0	.003	M.

Normal Equations:

$$+ 9.3000\,c + 1.7680\,\mu + 0.9647\,\pi = + 0.2255.$$
$$+ 28.6225 + 6.4955 = + 1.0329.$$
$$+ 5.5817 = + 0.3335.$$

Solution: $c = + 0″.016.$

$$\mu = + 0″.141 \pm 0″.005.$$
$$\pi = + 0″.103 \pm 0″.012.$$

p. e. unit weight, ± 0″.024.

Comparison Stars.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+168.9	+128.9	+0.174	0.59	—5°.1126
3	144.4	6.4	.222	0.59	—5°.1124
6	—243.4	+ 17.2	.166	0.57	
7	+162.3	58.6	.252	0.44	
8	—232.2	59.6	.186	0.49	—6°.1045
π	+ 18.8	+ 4.9		0.46	—5°.1123

No. 18.   B.D. + 8°.866.   OΣ 98 = 14 Orionis.   (5^h 2^m.5 ; + 8° 22'.)
Mag. 6.0-6.8. $\mu = +$ 0^s.0017 ; — 0".061.   Spectrum F.

The measures are in longitude. This is a binary of very long period. The components are separated about 0".9. Their combined images formed a very slightly elongated image. The attempt was to bisect this image.

No other parallaxes of this star have been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Feb. 19, 1915...	+0 10	P.	—4.56	—0.954	—0.206	.7	—0.007	Be.
Feb. 21, 1915...	0 36	M.	4.54	.962	.225	.9	+ .012	Be.
Oct. 11, 1915...	+0 50	M.	—2.22	+0.841	.190	.9	—0.014	Be.
Nov. 6, 1915...	—0 17	P.	1.96	.517	.209	.5	+0.005	Be.
Nov. 9, 1915...	+0 34	P.	1.93	.472	.205	.8	.001	Be.
Oct. 7, 1916...	+0 32	M.	+1.40	+0.870	.200	.5	+0.001	Be.
Oct. 14, 1916...	0 27	M.	1.47	.804	.212	.8	.013	Be.
Oct. 24, 1916...	—0 30	P.	1.57	.687	.020	1.0	.002	Be.
Jan. 28, 1917...	+0 17	M.	+2.53	—0.787	.190	1.0	—0.014	Be.
Feb. 12, 1917...	0 46	M.	2.68	.917	.211	.5	+0.007	Be.
Feb. 18, 1917...	0 29	M.	2.74	.951	.215	.8	.011	Be.
Feb. 21, 1917...	0 7	P.	2.77	.965	.198	1.0	—0.005	Be.

Normal Equations:

$$+ 9.4000\,c + 0.4780\,\mu — 1.3467\,\pi = — 1.9233.$$
$$+ 71.2869 — 1.2843 = — 0.0118.$$
$$+ 6.4805 = + 0.2959.$$

Solution: $c = — 0".204.$

$$\mu = + 0".006 \pm 0".004.$$
$$\pi = + 0".016 \pm 0".012.$$

p. e. unit weight, $\pm$ 0".031.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	189.6	152.0	0.182	0.76	+8°.861
9	+148.0	106.4	.211	0.71	+8°.871
11	200.0	— 59.2	.295	0.54	
13	—187.2	—104.4	.312	0.38	
π	0.0	0.0		0.60	+8°.866

No. 19. B.D. + 39°.1248. λ Aurigae = Σ 3, App. II. (5ʰ 12ᵐ.1; + 40° 1′.) Mag. 4.85. $\mu = + 0^s.0461$; — 0″.656. Spectrum G.

This is a quadruple star, but it is probable that it is not a physical system. The component A has a large proper motion, and this is the only component that we measured. The measures are in longitude. Other published parallaxes are:

Flint,	+ 0″.070 ± 0″.028.
Chase,	+ 0″.11 ± 0″.041.
Kostinsky,	+ 0″.10 ± 0″.021.
Millosevich,	+ 0″.111 ± 0″.015.
Adams,	+ 0″.100.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution. m.	Wt., p.	Res., v.	Measured by.
Oct. 7, 1912...	0 0	M.	—5.54	+0.907	—0.003	.7	0.000	Sm.
Oct. 20, 1912...	—0 27	B.	5.41	.788	+0.002	.8	—0.003	Sm.
Feb. 4, 1914...	0 34	P.	—0.69	—0.812	+0.092	.8	+0.012	Sm.
Feb. 9, 1914...	0 24	S.	0.64	.859	.102	1.0	.002	Sm.
Feb. 21, 1914...	+0 4	M.	0.52	.944	.111	.9	—0.005	Sm.
Mar. 3, 1914...	0 15	M.	0.42	.984	.116	.5	.007	Sm.
Sept. 28, 1914...	—0 50	P.	+1.67	+0.965	+0.189	.7	+0.005	Sm.
Sept. 30, 1914...	0 20	M.	1.69	.955	.202	.5	—0.007	Sm.
Oct. 19, 1914...	+0 4	P.	1.88	.804	.192	.7	+0.006	Sm.
Oct. 28, 1914...	—0 9	M.	1.97	.701	.202	.9	—0.003	Sm.
Feb. 8, 1915...	—0 28	P.	+3.00	—0.848	+0.205	.9	—0.001	Sm.
Feb. 10, 1915...	+0 5	P.	3.02	.866	.206	1.0	.002	Sm.

Normal Equations:

$$+ 9.4000\,c + \ 0.7470\,\mu - 0.8674\,\pi = + 1.2730.$$
$$+ 72.5882 \ - 5.9503 \ \ = + 1.9887.$$
$$+ 7.0239 \ \ = - 0.1746.$$

Solution:

$$c = + 0″.135.$$
$$\mu = + 0″.128 \pm 0″.002.$$
$$\pi = + 0″.070 \pm 0″.007.$$

p. e. unit weight, ± 0″.017.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	+146.6	− 38.3	+0.199	0.44	+40°.1252
5	−248.9	22.2	.184	0.56	+39°.1237
6	+ 0.6	+ 73.6	.215	0.52	+39°.1249
7	31.5	169.1	.235	0.46	
10	70.3	−182.3	.167	0.62	+40°.1248
π	2.8	+ 13.2		0.66	+39°.1248

No. 20. B.D. − 3°.1123. Weisse I 5^h.592. (5^h 26^m.4; − 3° 42′.)
Mag. 8.7. $\mu = + 0^s$.0496; − 2″.094. Spectrum Ma.

The measures were in longitude. Other published parallaxes are:

Schlesinger, + 0″.189 ± 0″.010.
Flint,   + 0″.06 ± 0″.036.
Kinberg,   + 0″.139 ± 0″.065.
Adams,   0″.158.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Nov. 1, 1913...	+0 18	M.	−6.13	+0.661	−0.500	.5	+0.017	M.
Nov. 5, 1913...	0 1	S.	6.09	.607	.483	.8	.000	M.
Feb. 2, 1914...	+0 20	S.	−5.20	−0.777	−0.481	1.0	−0.005	M.
Mar. 12, 1914...	1 14	M.	4.82	.994	.492	0.9	+0.016	M.
Mar. 13, 1914...	−0 22	M.	4.81	.994	.470	.7	−0.005	M.
Nov. 4, 1914...	−0 41	M.	−2.45	+0.624	−0.311	1.0	−0.007	M.
Nov. 13, 1914...	+0 45	M.	2.36	.495	.302	.9	.016	M.
Oct. 21, 1916...	+0 9	M.	+4.72	+0.789	−0.005	.9	+0.018	M.
Oct. 28, 1916...	0 20	M.	4.79	.709	+0.018	.8	−0.005	M.
Nov. 3, 1916...	−0 11	Ma.	4.85	.630	.013	.8	+0.001	M.
Jan. 28, 1917...	+0 48	M.	−5.71	−0.723	−0.027	.8	−0.017	M.
Feb. 11, 1917...	0 55	M.	5.85	.867	.011	.6	+0.001	M.
Feb. 22, 1917...	0 22	M.	5.96	.943	.009	1.0	.006	M.

Normal Equations:

$$+ 10.700\,c + 0.582\,\mu - 0.741\,\pi = − 2.415.$$
$$+ 262.981 \quad +0.683 \quad = + 11.821.$$
$$+ 6.347 \quad = + 0.396.$$

Solution:

$$c = -0''.226.$$
$$\mu = +0''.213 \pm 0''.002.$$
$$\pi = +0''.146 \pm 0''.014.$$

p. e. unit weight, $\pm 0''.036$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	-126.3	$+ 5.8$	$+0.614$	0.50	$-3°.1118$
2	$+148.8$	7.7	.822	0.55	$-3°.1127$
9	$- 22.6$	-13.5	-0.436	0.45	$-3°.1119$
π	$+ 54.7$	$+15.7$		0.85	$-3°.1123$

No. 21. B.D.—13°.2267. β 101 = 9 Argus. (7^h 47^m.1; — 13° 38'.)
Mag. 5.6–6.7. $\mu = -0^s.0041$; — ''.339. Spectrum F$_8$.

The measures are in right ascension. This is a binary with a period of about 23 years. The components are separated about 0''.25. The combined image seemed round and was bisected in the measuring. Other parallaxes published are by:

Flint, $+0''.028 \pm 0''.026$, (Transits).
Russell, $+0''.068$, (Hypothetical).

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas-ured by.
Mar. 14, 1915...	+0 52	M.	-4.06	-0.83	-0.298	1.0	$+0.004$	M.
Mar. 27, 1915...	-0 3	Ma.	3.93	.94	.296	1.0	-0.001	M.
Nov. 24, 1915...	+1 37	M.	-1.51	$+0.78$	-0.254	.5	$+0.004$	M.
Nov. 27, 1915...	-0 8	M.	1.48	.73	.250	.6	-0.001	M.
Nov. 29, 1915...	0 0	S.	1.46	.72	.247	1.0	.005	M.
Nov. 30, 1915...	-0 18	P.	1.45	.71	.246	1.0	.006	M.
Mar. 23, 1916...	-0 6	M.	-0.31	-0.91	-0.293	.5	$+0.001$	M.
Apr. 10, 1916...	+0 54	P.	0.13	.99	.297	1.0	.003	M.
Nov. 19, 1916...	-0 11	P.	$+2.10$	$+0.81$	-0.256	.5	$+0.011$	M.
Nov. 27, 1916...	0 0	M.	2.18	.73	.250	1.0	.003	M.
Mar. 24, 1917...	+0 8	Ma.	$+3.35$	-0.92	-0.307	.7	$+0.019$	M.
Mar. 25, 1917...	0 10	M.	3.36	.93	.280	.8	-0.008	M.
Mar. 28, 1917...	-0 10	P.	3.39	.94	.277	1.0	.012	M.

Normal Equations:

$$+ 10.6000\,c - 1.1750\,\mu - 2.1500\,\pi = -2.9014.$$
$$+ 74.0188 - 1.3860 = + 0.3629.$$
$$+ 7.6420 = + 0.7721.$$

Solution:

$$c = -0''.268.$$
$$\mu = + 0''.005 \pm 0''.003.$$
$$\pi = + 0''.121 \pm 0''.009.$$

p. e. unit weight, $\pm$ 0''.025.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
6	+273.6	+ 82.8	+0.223	0.45	
7	— 67.2	226.0	.258	0.35	—13°.2262
8	23.2	— 77.2	.253	0.47	
10	168.8	215.6	.266	0.36	—13°.2258
π	0.0	0.0		0.73	—13°.2267

No. 22.   B.D. + 27°.1589.   χ Cancri.   (8^h 14^m; + 27° 33'.)
Mag. 5.16. $\mu = - 0^s.0009; - 0''.388$.   Spectrum F.

The measures are in right ascension. The star has a large proper motion. No other parallaxes have been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Oct. 28, 1916...	—0 11	M.	—2.85	+0.96	+0.025	.5	—0.008	Sm.
Nov. 19, 1916...	0 1	P.	2.63	.86	.016	1.0	.000	Sm.
Nov. 21, 1916...	0 43	P.	2.61	.85	.016	.5	.000	Sm.
Mar. 30, 1917...	—0 32	M.	—1.32	—0.90	—0.020	.6	+0.013	Sm.
Apr. 3, 1917...	+0 18	M.	1.28	.93	.006	.5	—0.001	Sm.
Apr. 11, 1917...	0 23	P.	1.20	.97	.004	1.0	.004	Sm.
Nov. 3, 1917...	—0 18	M.	+0.86	+0.95	+0.012	.5	+0.005	Sm.
Nov. 4, 1917...	0 38	P.	.87	.94	.016	.9	.001	Sm.
Dec. 10, 1917...	0 32	P.	1.23	.65	.012	.6	.001	Sm.
Mar. 7, 1918...	+0 38	M.	+2.10	—0.69	—0.009	.5	+0.005	Sm.
Mar. 16, 1918...	0 28	Ma.	2.19	.79	0.000	.5	—0.006	Sm.
Mar. 29, 1918...	—0 48	P.	2.32	.89	—0.012	.5	+0.005	Sm.
Apr. 1, 1918...	0 16	M.	2.35	.91	.002	1.0	—0.005	Sm.

Normal Equations:

$$+ 8.6000\,c - 0.3860\,\mu - 0.5940\,\pi = + 0.0326.$$
$$+ 32.4643 \quad - 5.4033 \quad\; = -0.0756.$$
$$+ 6.6952 \quad\; = + 0.0842.$$

Solution:

$$c = + 0''.005.$$
$$\mu = - 0''.001 \pm 0''.003.$$
$$\pi = + 0''.060 \pm 0''.006.$$

p. e. unit weight, $\pm\, 0''.015$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	−212.8	+ 3.2	+0.046	0.64	
4	216.4	107.2	.247	1.03	+27°.1582
7	+ 69.2	− 22.4	.313	0.79	+27°.1591
8	96.4	24.8	.339	0.61	
11	162.4	207.2	.055	0.68	+27°.1593
π	0.0	0.0		0.83	+27°.1589

No. 23.   B.D. $+ 42°.1922.$ $\Sigma\ 1263 =$ Lalande 17161.   ($8^h\ 38^m.6$; $+ 42°\ 3'.$)   Mag. 8.5. $\mu = - 0^s.0241$; $- 0''.649.$

The measures are in right ascension. Other parallaxes published for this star are:

Chase, $- 0''.08\ \pm 0''.048$, (Heliometer).
Adams, $0''.058$,   (Spectroscopic).

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Mar. 23, 1916...	+0 7	M.	−4.54	−0.80	+0.086	.6	−0.014	Sm.
Nov. 27, 1916...	−0 3	M.	−2.05	+0.84	+0.070	1.0	+0.007	Sm.
Dec. 2, 1916...	0 24	M.	2.00	.80	.091	0.6	−0.015	Sm.
Dec. 9, 1916...	0 35	M.	1.93	.72	.064	.8	+0.009	Sm.
Mar. 25, 1917...	+0 7	M.	−0.87	−0.81	+0.024	.5	+0.002	Sm.
Mar. 28, 1917...	−0 15	P.	.84	.83	.019	.9	.006	Sm.
Mar. 30, 1917...	0 13	M.	.82	.85	.019	1.0	.005	Sm.
Nov. 17, 1917...	−0 54	M.	+1.50	+0.90	+0.022	0.6	+0.012	Sm.
Nov. 17, 1917...	0 20	M.	1.50	.90	.040	.6	−0.006	Sm.
Dec. 10, 1917...	0 5	P.	1.73	.71	.037	1.0	.010	Sm.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Mar. 22, 1918...	—0 11	P.	+2.75	—0.78	—0.022	1.0	+0.004	Sm.
Mar. 28, 1918...	0 44	M.	2.81	.84	.006	0.6	—0.014	Sm.
Mar. 29, 1918...	0 33	P.	2.82	.84	.024	.6	+0.004	Sm.

Normal Equations:

$$+ 9.8000\,c + 0.1290\,\mu - 0.5840\,\pi = + 0.3097.$$
$$+ 46.3998\quad - 2.0719\quad = - 0.6176.$$
$$+ 6.4901\quad = + 0.1500.$$

Solution:
$$c = + 0''.033.$$
$$\mu = - 0''.058 \pm 0''.004.$$
$$\pi = + 0''.104 \pm 0''.011.$$

p. e. unit weight, $\pm$ 0''.028.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
4	+ 80.9	— 97.7	+0.232	0.37	
5	—101.9	112.7	.127	0.52	
9	233.8	+103.7	.262	0.46	
13	+145.3	25.9	.379	0.40	
π	0.0	0.0		0.75	+42°.1922

No. 24.   B.D. + 42°.2214.   OΣ 234.   (11^h 26^m.2 + 41° 52'.)
Mag. 7.0–7.5.

The measures are in right ascension. The combined image of the two components, which are separated about 0''.4, appears round. This is a binary with a period of 77 years, (See). Russell finds for this star a hypothetical parallax of 0''.014.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
May 10, 1915...	—0 18	P.	—5.50	—0.79	+0.024	.9	0.000	Sm.
Jan. 8, 1916...	+0 5	M.	—3.07	+0.80	.054	.8	+0.007	Sm. Be.
Apr. 30, 1916...	—0 7	M.	—1.94	—0.71	.073	1.0	—0.013	Sm.
May 11, 1916...	+0 2	M.	1.83	.81	.070	1.0	.010	Be.
May 12, 1916...	—0 17	P.	1.82	.81	.050	.9	+0.010	Sm. Be.
May 13, 1916...	+0 6	Ma.	1.81	.82	.059	.5	.001	Sm.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Dec. 9, 1916...	—0 13	M.	+0.29	+0.90	.096	.6	—0.001	Be.
Dec. 23, 1916...	0 4	M.	0.43	.89	.092	.5	+0.004	Be.
Dec. 30, 1916...	0 28	M.	0.50	.86	.102	.5	—0.006	Sm.
Jan. 19, 1917...	0 18	Ma.	0.70	.70	.092	1.0	+0.005	Sm.
Apr. 16, 1917...	—0 35	P.	+1.57	—0.54	.099	.7	—0.003	Be.
May 11, 1917...	0 13	P.	1.82	.80	.083	.7	+0.013	Sm.
May 14, 1917...	0 0	P.	1.85	.83	.090	.7	.006	Be.
Jan. 5, 1918...	+0 9	M.	+4.21	+0.82	.146	.7	—0.014	Sm.
Feb. 11, 1918...	—0 5	P.	4.58	.43	.130	.7	+0.003	Sm.

Normal Equations:

$$+ 11.2000\,c — 2.5590\,\mu — 1.2590\,\pi = + 0.9125.$$
$$+ 80.7848 + 9.0348 = + 0.6481.$$
$$+ 6.6369 = + 0.0361.$$

Solution:

$$c = + 0''.085.$$
$$\mu = + 0''.046 \pm 0''.003.$$
$$\pi = + 0''.038 \pm 0''.011.$$

p. e. unit weight, $\pm 0''.025$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	—120.8	+192.9	+0.222	0.40	
4	10.1	—204.5	.368	0.36	+41°.2199
7	+ 70.6	+255.9	.146	0.46	
8	76.3	— 18.6	.264	0.36	
π	0.0	0.0		0.62	+42°.2214

No. 25.   B.D. + 28°.2106.   Bradley 1646 = 9 Comae Berenices.
($12^h\ 14^m.5$; + 28° 43′.)   Mag. 6.30. $\mu = — 0^s.0151$; — 0″.142.
Spectrum F.

The measures are in right ascension.   No other parallaxes have been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Jan. 8, 1916...	+0 22	M.	—2.38	+0.87	—0.060	.7	—0.016	Sm.
Jan. 14, 1916...	0 16	Ma.	2.32	.86	.085	.5	+0.008	Be.
Feb. 7, 1916...	—1 16	S.	2.08	.66	.079	1.0	—0.002	Be.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
May 11, 1916...	—0 4	M.	—1.14	—0.68	.113	.6	+0.010	Be.
May 12, 1916...	+0 15	P.	1.13	.70	.110	.5	.007	Be.
May 13, 1916...	0 16	Ma.	1.12	.70	.094	1.0	—0.009	Be.
May 26, 1916...	0 14	P.	0.99	.82	.113	1.0	.008	Be.
Dec. 23, 1916...	—0 1	M.	+1.12	+0.90	.117	.5	+0.010	Be.
Jan. 26, 1917...	0 27	Ma.	1.46	.75	.114	.9	.003	Sm.
Feb. 12, 1917...	+0 14	M.	1.63	.59	.105	.5	—0.009	Be.
Feb. 12, 1917...	0 54	M.	1.63	.59	.118	.9	+0.004	Be.
May 17, 1917...	+0 20	M.	+2.57	—0.73	.130	.5	—0.006	Be.
May 30, 1917...	0 49	P.	2.70	.84	.132	1.0	.006	Be.

Normal Equations:

$$+ 9.6000\,c — 0.1240\,\mu + 0.1670\,\pi = — 1.0101.$$
$$+ 31.4931 — 1.7336 = — 0.2780.$$
$$+ 5.3907 = + 0.0529.$$

Solution:

$$c = — 0''.106.$$
$$\mu = — 0''.041 \pm 0''.004.$$
$$\pi = + 0''.048 \pm 0''.011.$$

p. e. unit weight, $\pm\,0''.025$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	— 28.8	—178.8	+0.238	0.69	+28°.2105
3	81.2	82.8	.332	0.90	+28°.2103
4	+ 42.4	+202.0	.327	0.53	
6	195.2	38.0	.103	0.43	
π	0.0	0.0		0.66	+28°.2106

No. 26.   B.D. + 26°.2345.   Σ 1639 = 68 Comae Berenices.
(12ʰ 19ᵐ.4; + 26° 8'.)   Mag. 6.7–7.9.   Spectrum A₅.

The measures are in right ascension. This is a binary of long and uncertain period. The combined image of the components was sensibly round. Russell finds a hypothetical parallax of 0″013 for this star.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
May 6, 1915...	—0 10	M.	—5.95	—0.60	+0.040	.6	+0.015	Be.
May 23, 1915...	+0 27	M.	5.78	.78	.044	.7	.012	Be.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Feb. 3, 1916...	—0 27	P.	—3.22	+0.70	.048	1.0	—0.007	Be.
May 11, 1916...	+1 0	M.	—2.24	—0.67	.057	.9	—0.013	Be.
June 1, 1916...	0 45	M.	2.03	.85	.043	.9	+0.002	Be.
Jan. 19, 1917...	—0 29	Ma.	+0.29	+0.82	.032	.5	—0.004	Be.
Jan. 19, 1917...	+0 7	Ma.	0.29	.82	.034	1.0	.006	Be.
Feb. 24, 1917...	—0 34	M.	0.65	.44	.036	.5	.007	Be.
Feb. 24, 1917...	+0 6	M.	0.65	.44	.023	1.0	+0.006	Be.
May 10, 1917...	+0 57	M.	+1.40	—0.66	.042	1.0	—0.009	Be.
Jan. 5, 1918...	+0 1	M.	+3.80	+0.89	.008	.5	+0.008	Sm.
Jan. 5, 1918...	0 41	M.	3.80	.89	.010	.8	.006	Sm.
Feb. 13, 1918...	—0 5	Ma.	4.19	.59	.008	.5	.009	Sm.
Feb. 15, 1918...	0 15	Ma.	4.21	.56	.014	1.0	.003	Sm.

Normal Equations:

$$10.9000\,c - 0.6240\,\mu + 1.6680\,\pi = +0.3558.$$
$$+ 111.2145 + 13.7995 = -0.4476.$$
$$+ 5.4381 = -0.0199.$$

Solution:

$$c = + 0''.033.$$
$$\mu = -0''.014 \pm 0''.003.$$
$$\pi = -0''.028 \pm 0''.014.$$

p. e. unit weight, ± 0''.026.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	— 64.4	+206.0	+0.380	1.31	+26°.2343
2	+ 94.0	65.0	.173	0.58	+26°.2346
3	101.6	— 17.6	.156	0.87	+26°.2347
4	— 26.4	298.0	.291	0.63	+25°.2503
π	0.0	0.0		0.86	+26°.2345

No. 27. B.D. + 10°.2468. 33 Virginis = Br 1706. (12^h 41^m.3; + 10° 6'.) Mag. 5.86. $\mu = + 0^s$.0184; — 0''.456. Spectrum K.

The measures are in longitude. Other published parallaxes are by:

Chase, —0''.10 ± 0''.016.
Adams, 0''.030.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days. T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas-ured by.
May 19, 1912...	+0 34	B.	—4.41	—0.810	+0.152	.8	—0.004	S.
May 27, 1912...	1 6	B.	4.33	.885	.157	.9	.012	S.
Feb. 4, 1913...	—0 12	B.	—1.80	+0.751	+0.064	1.0	—0.009	S.
Feb. 6, 1913...	0 6	B.	1.78	.729	.061	.7	.007	S.
Feb. 7, 1913...	+0 49	M.	1.77	.716	.059	.5	.005	S.
Feb. 14, 1913...	0 34	M.	1.70	.629	.043	.8	+0.010	S.
Feb. 25, 1913...	0 7	B.	1.59	.472	.045	.9	.004	S.
May 3, 1913...	—0 21	M.	—0.92	—0.613	+0.039	.7	—0.008	S.
May 8, 1913...		M.	0.87	.679	.008	.9	+0.022	S.
May 14, 1913...	—0 36	B.	0.81	.751	.014	.9	.014	S.
June 2, 1913...	+0 16	B.	0.62	.929	.003	.4	.020	S.
Jan. 5, 1914...	+0 35	M.	+1.55	+0.969	—0.052	.9	—0.006	S.
Feb. 1, 1914...	0 27	P.	1.82	.786	.070	.9	+0.004	S.
Feb. 7, 1914...	—0 14	S.	1.88	.720	.069	1.0	.001	S.
Feb. 17, 1914...	0 3	M.	1.98	.592	.070	.9	0.000	S.
Feb. 24, 1914...	+0 7	P.	2.05	.491	.078	.9	+0.006	S.
May 2, 1914...	+0 6	M.	+2.72	—0.596	—0.099	1.0	+0.008	S.
May 14, 1914...	0 54	M.	2.84	.749	.097	.9	.003	S.
May 15, 1914...	0 19	P.	2.85	.760	.094	.9	0.000	S.
May 25, 1914...	0 24	S.	2.95	.862	.064	.9	—0.033	S.

Normal Equations:

$$+ 16.800\,c + 2.485\,\mu - 0.442\,\pi = - 0.118.$$
$$+ 91.850 + 1.769 = - 3.074.$$
$$+ 8.971 = - 0.093.$$

Solution:

$$c = - 0''.002.$$
$$\mu = - 0''.156 \pm 0''.004.$$
$$\pi = - 0''.018 \pm 0''.012.$$

p. e. unit weight, $\pm\ 0''.037.$

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	+61.7	— 98.0	+0.949	0.70	+10°.2467
2	—58.2	12.8	—0.199	0.62	+10°.2471
3	3.5	+110.8	+0.250	0.42	+10°.2472
π	+69.3	— 62.7		0.38	+10°.2468

No. 28. B.D. $+ 17°.2611.$ β 800. (13^h $11^m.9$; $+ 17°$ $33'$.)

Mag. 7.0–10. $\mu = + 0^s.0445$; $- 0''.269$.

The measures were in longitude. This is a binary star whose large proper motion and large orbital motion indicates that it is comparatively near to us. The measures were made on the principal component. Adams found a parallax of this star spectroscopically to be $0''.087$.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
June 4, 1915...	+0 3	P.	—4.28	—0.75	+0.025	.7	—0.001	Be.
June 5, 1915...	0 9	Ma.	4.27	.77	.023	.8	+0.001	Be.
Feb. 3, 1916...	—0 31	P.	—1.84	+0.83	.134	1.0	+0.001	Be.
Apr. 30, 1916...	+0 10	S.	—0.97	—0.35	.142	.5	+0.007	Be.
May 26, 1916...	0 27	P.	0.71	.68	.167	.5	—0.014	Be.
June 1, 1916...	0 48	M.	0.65	.73	.147	.7	+0.008	Be.
Jan. 26, 1917...	—0 38	Ma.	+1.74	+0.87	.255	.5	+0.010	Be.
Jan. 26, 1917...	0 0	Ma.	1.74	.87	.264	.9	.001	Be.
Feb. 12, 1917...	+0 55	M.	1.91	.75	.269	.9	0.000	Be.
Mar. 12, 1917...	0 28	M.	2.19	.41	.283	.6	—0.009	Be.
Mar. 12, 1917...	1 13	M.	2.19	.41	.280	.5	.006	Be.
May 30, 1917...	0 35	P.	+2.98	—0.72	.282	.8	+0.003	Be.

Normal Equations:

$$+ 8.4000 c - 0.5990 \mu + 0.4310 \pi = + 1.5699.$$
$$+ 51.7150 + 6.7732 = + 1.8534.$$
$$+ 4.3880 = + 0.3910.$$

Solution: $\quad$ $c = + 0''.189.$

$$\mu = + 0''.169 \pm 0''.003.$$
$$\pi = + 0''.070 \pm 0''.010.$$

p. e. unit weight, $\pm 0''.018.$

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—215.2	— 37.2	+0.451	0.43	
2	82.4	+178.0	.162	0.68	$+18°.2707$
5	+212.0	218.8	.045	0.51	$+18°.2711$
7	294.2	— 62.4	.042	0.41	
π	0.0	0.0		0.60	$+17°.2611$

No. 29. B.D. + 35°.2462.   OΣ 269.   (13^h 28^m.3 + 35° 25′.)
Mag. 7.2–7.7.

This is a binary star. The combined image of the components, which is round, was bisected in the measurements. The measures are in right ascension. No other parallax of the star has been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Mar. 3, 1915...	+0 50	Ma.	—7.48	+0.61	—0.060	.5	+0.006	Be.
Mar. 12, 1915...	0 8	M.	7.39	.49	.054	.8	—0.002	Be.
Feb. 7, 1916...	+0 15	S.	—4.07	+0.83	.050	.8	—0.008	Be. Sm.
Mar. 23, 1916...	0 26	P.	3.62	.32	.062	.9	.004	Be. Sm.
June 12, 1916...	+0 20	P.	—2.81	—0.79	.088	1.0	+0.005	Be.
June 18, 1916...	0 55	S.	2.75	.84	.090	.5	.006	Be.
Mar. 3, 1918...	—0 36	P.	+3.48	+0.60	.086	.8	+0.012	Sm.
Mar. 3, 1918...	1 10	P.	3.48	.60	.070	.8	—0.004	Sm.
Mar. 15, 1918...	+0 55	Ma.	3.60	.44	.084	1.0	+0.007	Sm.
May 17, 1918...	+0 10	D.	+4.23	—0.50	.080	1.0	—0.012	Sm.
May 31, 1918...	0 0	D.	4.37	.68	.103	.5	+0.009	Sm.
June 7, 1918...	0 45	P.	4.44	.74	.096	.9	.001	Sm.
June 19, 1918...	1 13	D.	4.56	.85	.090	.6	—0.007	Sm.

Normal Equations:

$$+ 10.1000\,c + 1.9640\,\mu - 0.1770\,\pi = - 0.7811.$$
$$+ 198.3845 - 9.5071 = - 0.6450.$$
$$+ 4.1754 = + 0.0908.$$

Solution:
$$c = - 0''.077.$$
$$\mu = - 0''.008 \pm 0''.002.$$
$$\pi = + 0''.067 \pm 0''.012.$$

p. e. unit weight, $\pm$ 0″.023.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—211.9	—248.3	+0.169	0.50	
2	61.9	200.7	.217	0.44	
5	+ 8.6	+224.1	.301	0.41	
6	149.3	57.9	.313	0.59	
π	0.0	0.0		0.84	+35°.2462

No. 30. B.D. + 30°.2653. η Coronae Borealis = Σ 1937.
(15ʰ 19ᵐ.1; + 30° 39′.) Mag. 5.58–6.08. μ = + 0ˢ.0101;
— 0″.198. Spectrum G.

This is a binary system with a period of 41.5 years. In making the measures the combined image of the components was bisected. It seemed perfectly round. The measures are in right ascension. Other parallaxes of this star published are:

>Slocum, (Photographic), + 0″.073 ± 0″.014.
>Russell, (Hypothetical), + 0″.060.
>Adams, (Spectroscopic), + 0″.069.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Mar. 23, 1916...	—0 10	P.	—4.42	+0.72	+0.011	.9	+0.002	Be.
June 12, 1916...	—0 1	P.	—3.61	—0.47	—0.004	.8	+0.004	Be.
June 26, 1916...	0 24	P.	3.47	.67	.003	1.0	.001	Be.
July 4, 1916...	0 20	S.	3.39	.76	+0.002	.8	—0.005	Sm.
Mar. 22, 1917...	—1 18	P.	—0.78	+0.73	+0.041	.5	+0.011	Be.
Mar. 24, 1917...	1 13	M.	0.76	.71	.050	1.0	.002	Be.
Mar. 24, 1917...	+0 5	M.	0.76	.71	.060	1.0	—0.008	Be.
July 7, 1917...	+0 3	Ma.	+0.29	—0.78	+0.037	.6	—0.001	Sm.
Mar. 1, 1918...	+0 23	Ma.	+2.66	+0.90	+0.098	.9	—0.007	Sm.
Mar. 3, 1918...	—0 2	P.	2.68	.89	.086	1.0	+0.005	Sm.
June 20, 1918...	+1 18	D.	+3.77	—0.58	+0.080	.6	—0.004	Sm.
June 27, 1918...	0 16	P.	3.84	.68	.066	.6	+0.009	Sm.
July 8, 1918...	0 25	D.	3.85	.79	.077	.5	—0.003	Sm.

Normal Equations:

$$+ 10.2000\,c - 3.1690\,\mu + 0.8600\,\pi = + 0.4583.$$
$$+ 89.4797 + 1.4805 = + 0.8298.$$
$$+ 5.5064 = + 0.1559.$$

Solution:

$$c = + 0''.047.$$
$$\mu = + 0''.050 \pm 0''.002.$$
$$\pi = + 0''.085 \pm 0''.008.$$

p. e. unit weight, ± 0″.018.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+133.8	+144.5	+0.341	0.60	+31°.2731
3	230.1	112.9	.150	0.68	+30°.2654
6	101.0	−125.6	.039	0.47	
12	−178.9	130.5	.470	0.40	
π	0.0	0.0		0.97	+30°.2653

No. 31. B.D. + 2°.3118. λ Ophiuchi = Σ 2055. (16^h 25^m.9; + 2° 12'.) Mag. 3.85. $\mu = -0^s.0032$; $-0''.084$. Spectrum A.

The measures are in longitude. This is a binary of long period. The combined image of the two components is very slightly elongated. In the measures this combined image was bisected. Other published parallaxes are:

Lee-Joy-Van Biesbroeck, (Photographic), $+0''.018 \pm 0''.003$.
Schlesinger, (Photographic), $-0''.010 \pm 0''.008$.
Russell, (Hypothetical), $+0''.024$.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Apr. 14, 1915...	−0 32	Ma.	−3.16	+0.645	−0.028	1.0	+0.003	Be.
Apr. 15, 1915...	0 28	P.	3.15	.632	.021	.8	−0.003	Be.
July 8, 1915...	+0 56	Ma.	−2.31	−0.671	.026	1.0	−0.003	Be.
July 9, 1915...	−0 9	M.	2.30	.684	.023	1.0	0.000	Be.
July 14, 1915...	0 6	M.	2.25	.745	.022	.8	−0.001	Be.
July 16, 1915...	+0 13	M.	2.23	.767	.022	.9	.001	Be.
Mar. 23, 1916...	0 28	P.	+0.28	+0.871	.024	1.0	−0.002	Be.
June 29, 1916...	0 14	S.	+1.26	−0.561	.019	.6	−0.006	Be.
July 7, 1916...	−0 30	S.	1.34	.668	.028	1.0	+ .004	Be.
Apr. 13, 1917...	+0 14	Ma.	+4.14	+0.650	.024	1.0	−0.003	Be.
Apr. 16, 1917...	−0 8	M.	4.17	.611	.030	.9	+0.004	Be.
Apr. 16, 1917...	+0 19	M.	4.17	.611	.027	1.0	.001	Be.

Normal Equations:

$$+ 11.0000\,c + 0.3420\,\mu + 0.1866\,\pi = -0.2726.$$
$$+ 90.0804 + 8.8293 = -0.0450.$$
$$+ 5.1526 = -0.0116.$$

Solution:

$$c = -0''.025.$$
$$\mu = -0''.015 \pm 0''.001.$$
$$\pi = -0''.037 \pm 0''.005.$$

p. e. unit weight, $\pm 0''.010$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
I	+ 28.8	—164.8	+0.275	0.80	+2°.3119
2	—134.4	13.6	.245	0.81	+2°.3115
4	151.1	+212.4	.266	0.60	+2°.3124
5	+215.2	— 10.4	.214	0.75	+2°.3114
π	0.0	0.0		0.95	+2°.3118

No. 32. B.D. + 32°.2896. 72 W Herculis. (17^h $16^m.9$; $+ 32°$ $36'$.)
Mag. 5.36. $\mu = + 0^s.0099$; $— 1''.053$. Spectrum G.

This is B. G. C. 7976. The brighter component only was measured. Other published parallaxes of this star:

Flint, (Transits),	$+0''.09 \pm 0''.041$.
Chase, (Heliometer),	$+0''.14 \pm 0''.036$.
Schlesinger, (Photometric),	$+0''.068 \pm 0''.009$.
Adams, (Spectroscopic),	$+0''.120$.

The measures are in longitude.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas-ured by.
July 25, 1915...	+0 30	M.	—7.90	—0.754	—0.126	.9	—0.001	Be.
Apr. 29, 1916...	+0 47	M.	—5.11	+0.568	—0.071	.9	0.000	Be.
May 1, 1916...	—0 12	S.	5.09	.541	.070	.7	—0.001	Be.
July 7, 1916...	—0 29	W.	—4.42	—0.530	—0.086	.6	+0.010	Be.
July 11, 1916...	+0 17	S.	4.38	.587	.084	.8	.007	Be.
Aug. 19, 1917...	+0 38	M.	—.034	—0.965	—0.021	1.0	—0.005	Sm.
Aug. 26, 1917...	—0 25	M.	0.27	.992	.028	.5	+0.002	Sm.
Aug. 27, 1917...	+0 49	M.	0.26	.995	.019	.9	—0.007	Sm.
May 2, 1918...	—0 50	P.	+2.22	+0.533	+0.044	.7	—0.015	Sm.
May 2, 1918...	—0 10	P.	2.22	.533	.034	.7	.005	Sm.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
July 25, 1918...	+1 2	D.	+3.06	—0.756	+0.024	.9	—0.001	Sm.
July 26, 1918...	+1 7	M.	3.07	.768	.013	.6	+0.010	Sm.
Apr. 13, 1919...	—0 10	P.	+5.68	+0.776	+0.079	.9	+0.001	Sm.
Apr. 19, 1919...	+0 39	D.	5.74	.707	.072	1.0	.008	Sm.
Apr. 22, 1919...	—0 41	P.	5.77	.669	.078	1.0	.001	Sm.

Normal Equations:

$$+\,12.1000\,c\,+\quad 2.1890\,\mu\,-\quad 1.2534\,\pi = -\,0.0921.$$
$$+\,241.3464\quad +\,15.0235\quad\ \ = +\,3.4880.$$
$$+\quad 6.5207\quad\ \ = +\,0.3057.$$

Solution:

$$c = -\,0''.009.$$
$$\mu = +\,0''.064 \pm 0''.001.$$
$$\pi = +\,0''.064 \pm 0''.009.$$

p. e. unit weight, $\pm\,0''.020.$

<div align="center">COMPARISON STARS.</div>

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	—168.5	— 51.5	+0.313	0.32	
6	+191.9	+ 29.1	.233	0.50	+32°.2901
8	80.4	— 42.0	.294	0.34	
12	— 97.1	+136.0	.160	0.26	+32°.2894
π	0.0	0.0		0.69	+32°.2896

No. 33.   B.D. — 0°.3300.   Σ 2173.   (17^h 25^m.2 ; — 0° 59'.)
Mag. 5.34. $\mu = -\,0^s.0083$; — $0''175.$ Spectrum G.

The measures are in longitude. This is a binary with a period of 46 years. The combined image of the two components was sensibly round and was bisected in the measures.

Russell gives a hypothetical parallax of + 0''.075.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Apr. 24, 1912...	+0 7	B.	—12.07	+0.713	+0.059	.9	—0.001	Be.
May 18, 1912...	0 25	B.	11.83	.378	.053	1.0	0.000	Be.
May 15, 1915...	0 0	P.	— 0.91	+0.435	—0.013	1.0	—0.002	Be.
May 19, 1915...	1 2	Ma.	0.87	.373	.014	.5	.002	Be.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas-ured by.
July 18, 1915...	—0 58	M.	— 0.27	—0.578	—0.033	.5	+0.003	Be.
July 23, 1915...	1 18	M.	0.22	.653	.035	.8	.003	Be.
Aug. 13, 1915...	+0 7	P.	0.01	.878	.030	.8	—0.006	Be.
Aug. 14, 1915...	1 6	Ma.	0.00	.887	.041	1.0	+0.005	Be.
Aug. 13, 1916...	0 41	M.	+ 3.65	—0.885	—0.049	.8	—0.010	Be.
Aug. 18, 1916...	0 3	P.	3.70	.923	.068	1.0	+0.009	Be.
Apr. 16, 1917...	0 10	M.	+ 6.11	+0.803	—0.062	.7	+0.006	Be.
May 12, 1917...	—0 4	M.	6.37	.473	.065	1.0	.004	Be.
May 12, 1917...	+0 35	M.	6.37	.473	.051	1.0	—0.010	Be.

Normal Equations:

$$+ 11.0000\,c - 0.7200\,\mu - 0.8870\,\pi = - 0.2900.$$
$$+ 403.9814 - 9.1128 = - 2.6380.$$
$$+ 5.1534 = + 0.1365.$$

Solution:

$$c = - 0''.026.$$
$$\mu = - 0''.030 \pm 0''.001.$$
$$\pi = + 0''.051 \pm 0''.009.$$

p. e. unit weight, $\pm$ 0''.019.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	+202.0	— 20.0	+0.197	0.57	—0°.3306
4	261.2	+111.6	.124	0.80	—0°.3307
5	— 66.8	206.0	.263	0.46	
9	132.0	—153.2	.416	0.76	—1°.3343
π	0.0	0.0		0.53	—0°.3300

No. 34.   B.D. + 30°.3128.   99b Herculis = Clark 15 = Br. 2278.
(18^h 3^m.2; + 30° 33'.)   Mag. 5.21. $\mu = - 0^s.0073; + 0''.063$.
Spectrum F_8.

The measures were in longitude. This is a binary with a period of 63 years, (Aitken). The components are separated by 1''.3 but appear to be perfectly round, perhaps because the fainter component did not impress itself on the plate on account of the rotating sector.

Other parallaxes published for this star are :

Flint, $+ 0''.064 \pm 0''.022$, (Transits).
Russell, $+ 0''.062$,   (Hypothetical).
Schlesinger, $0''.025 \pm 0''.006$, (Photographic).
Adams, $0''.105$,   (Spectroscopic).

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Aug. 18, 1915...	—o 13	P.	—3.88	—0.815	+0.069	.7	—0.001	Be.
Aug. 23, 1915...	o 16	P.	3.83	.861	.054	.9	+0.014	Sm.
Aug. 25, 1915...	o 11	P.	3.81	.878	.065	.5	.003	Be.
Apr. 30, 1916...	—o 4	P.	—1.32	+0.779	.070	1.0	+0.001	Be.
May 13, 1916...	o 10	M.	1.19	.623	.072	1.0	— .003	Be.
May 21, 1916...	+o 23	P.	1.11	.512	.084	.6	.017	Sm.
Aug. 28, 1916...	+o 6	P.	—0.12	—0.907	.052	.8	—0.002	Be.
Sept. 9, 1916...	o 27	Ma.	0.00	.975	.050	.9	.002	Be.
Sept. 10, 1916...	o 15	P.	+0.01	.978	.056	.9	.008	Sm.
May 12, 1917...	+o 52	M.	+2.45	+0.640	.038	.7	+0.013	Sm.
July 23, 1917...	+o 16	M.	+3.17	—0.494	.043	.7	—0.006	Sm.
Aug. 28, 1917...	—o 2	P.	3.53	.906	.030	1.0	+0.002	Sm.
May 16, 1918...	+o 33	P.	+6.14	+0.591	.029	.8	0.004	Sm.

Normal Equations:

$$+ 10.5000\,c + 1.0450\,\mu - 2.8895\,\pi = + 0.5687.$$
$$+ 88.7641 \quad + 4.5279 \quad\;\; = - 0.3269.$$
$$+ 6.6022 \quad\;\; = - 0.1268.$$

Solution: $c = + 0''.057.$

$\mu = - 0''.023 \pm 0''.003.$

$\pi = + 0''.043 \pm 0''.010.$

p. e .unit weight, $\pm 0''.024.$

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—244.4	— 50.0	+0.216	0.76	+30°.3119
5	+ 49.6	140.0	.204	0.79	+30°.3129
8	135.6	+162.0	.355	0.56	
10	— 24.8	— 80.4	.225	0.56	
π	0.0	0.0		0.65	+30°.3128

No. 35.   B.D. + 38°.3466.   Σ 2481 (π) ; Secchi 2 (π^1).   (19^h 7^m.7 ; 38° 36′.)   Mag. 8.0–8.0. $\mu = -0^s.0210$; $-0''.103$.

This is a triple star. We have designated the component A by π, and by π^1, the components B C, (Secchi 2), which are separated by $0''.24$, and whose combined image is sensibly round. In measuring π^1 we bisected the combined image of the components. The proper motion of A is not the same as that of B C. The measures are in longitude. The same comparison field was used for both components. Other parallaxes published are:

Russell, (Hypothetical), $+ 0''.021$.

Mitchell, (Photographic), π $+ 0''.019 \pm 0.010$.

π^1 $+ 0''.046 \pm 0.011$.

TABLE AND SOLUTIONS FOR π.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
May 18, 1914...	+0 10	M.	−3.86	+0.876	+0.080	.7	+0.001	M.
June 1, 1914...	0 8	M.	3.72	.736	.077	.5	.002	M.
Sept. 2, 1914...	−0 6	P.	−2.79	−0.675	+0.063	.7	−0.001	M.
Sept. 5, 1914...	0 15	P.	2.76	.712	.055	.5	+0.007	M.
May 9, 1915...	0 21	P.	−0.30	+0.942	+0.036	.5	0.000	M.
May 19, 1915...	+0 15	Ma.	0.20	.871	.041	.9	−0.006	M.
Aug. 23, 1915...	0 1	P.	+0.76	−0.546	+0.020	1.0	−0.003	M.
Sept. 10, 1915...	−0 10	S.	0.94	.773	.009	.9	+0.005	M.
Sept. 12, 1915...	+0 5	P.	0.96	.793	.022	.7	−0.008	M.
June 1, 1916...	−0 6	P.	+3.59	+0.730	−0.020	.9	+0.007	M.
June 12, 1916...	0 2	P.	3.70	.591	.022	1.0	.006	M.
June 13, 1916...	0 18	P.	3.71	.577	.006	.9	−0.010	M.

Normal Equations:

$$+ 9.200\,c + 4.323\,\mu + 1.377\,\pi = + 0.220.$$
$$+ 66.383 + 3.137 = - 0.700.$$
$$+ 4.912 = + 0.018.$$

Solution:

$$c = + 0''.029.$$
$$\mu = - 0''.059 \pm 0''.002.$$
$$\pi = + 0''.016 \pm 0''.009.$$

p. e. unit weight, $\pm 0''.019$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
I	+166.0	+26.8	+0.279	0.57	+38°.3473
5	74.4	—36.4	.305	0.54	+38°.3469
7	— 57.6	+94.4	.176	0.50	+38°.3463
13	243.2	—50.8	.240	0.44	
π	0.0	0.0		0.45	+38°.3466

TABLE AND SOLUTIONS FOR π'.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
May 18, 1914...	+0 10	M.	—3.64	+0.876	+0.038	1.0	+0.005	M.
June 1, 1914...	0 8	M.	3.50	.736	.034	.5	.008	M.
Aug. 18, 1914...	+0 8	P.	—2.72	—0.467	+0.042	.6	—0.007	M
Sept. 2, 1914...	—0 6	P.	2.57	.675	.032	.9	+0.002	M.
Sept. 5, 1914...	0 15	P.	2.54	.712	.037	.5	—0.003	M.
May 19, 1915...	+0 15	Ma.	+0.02	+0.871	+0.011	1.0	—0.012	M.
Aug. 23, 1915...	+0 1	P.	+0.98	—0.546	—0.012	1.0	+0.003	M.
Sept. 10, 1915...	—0 10	S.	1.16	.773	.016	.5	.005	M.
Sept. 12, 1915...	+0 5	P.	1.18	.793	.007	.5	—0.004	M.
June 1, 1916...	—0 6	P.	+3.81	+0.730	—0.050	1.0	+0.004	M.
June 12, 1916...	0 2	P.	3.92	.591	.051	.5	.004	M.
June 13, 1916...	0 18	P.	3.93	.577	.044	.5	—0.003	M.

Normal Equations:

$$+ 8.5000\,c - 0.7000\,\mu + 0.8563\,\pi = + 0.0175.$$
$$+ 65.2354 \quad + 2.3906 \quad = -0.7892.$$
$$+ 4.3766 \quad = -0.0378.$$

Solution:

$$c = + 0''.001.$$
$$\mu = - 0''.056 \pm 0''.002.$$
$$\pi = - 0''.011 \pm 0''.009.$$

p. e. unit weight, ± 0''.018.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
I	+166.0	+26.8	+0.278	0.57	+38°.3473
5	74.4	—36.4	.307	0.54	+38°.3469
7	— 57.6	+94.4	.172	0.50	+38°.3463
13	243.2	—50.8	.243	0.44	
π'	0.4	0.6		0.45	+38°.3466

No. 36. B.D. + 27°.3391. Σ 2525. (19ʰ 22ᵐ.5; + 27° 7'.)
Mag. 7.5. Spectrum G.

The measures are in longitude. This is a binary of long and uncertain period. The components are separated by about 0".5. The combined image of the components seemed slightly elongated. This image was bisected in the measures. Russell gives a hypothetical parallax of 0".025 for this star.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Aug. 25, 1915...	+0 10	P.	—3.59	—0.557	—0.155	.8	+0.007	Sm.
Sept. 7, 1915...	—0 3	P.	3.46	.725	.143	1.0	—0.005	Be.
Sept. 13, 1915...	+0 2	P.	3.40	.791	.155	.8	+0.008	Be.
May 20, 1916...	+0 14	M.	—0.90	+0.861	.115	.5	—0.011	Sm.
June 1, 1916...	—0 8	P.	0.78	.738	.126	.5	.000	Be.
June 4, 1916...	0 7	P.	0.75	.702	.141	.6	+0.015	Sm.
June 12, 1916...	+0 19	S.	0.67	.600	.117	.8	—0.008	Be.
Aug. 18, 1916...	+0 20	P.	—0.00	—0.465	.116	.9	—0.008	Sm.
Aug. 25, 1916...	0 37	P.	+0.07	.567	.122	.9	.002	Be.
Sept. 21, 1916...	0 52	M.	0.34	.872	.123	.8	.000	Be.
June 1, 1918...	—0 47	D.	+6.52	+0.743	.083	1.0	+0 006	Sm.
June 8, 1918...	0 56	D.	6.59	.660	.074	.9	— .003	Sm.

Normal Equations:

$$+ 9.5000\,c + 1.9080\,\mu - 0.3921\,\pi = - 1.1519.$$
$$+ 114.6285 + 13.4329 = + 0.5674.$$
$$+ 4.5374 = + 0.1503.$$

Solution:

$$c = - 0".122.$$
$$\mu = + 0".031 \pm 0".003.$$
$$\pi = + 0".013 \pm 0".013.$$

p. e. unit weight, ± ".023.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—163.6	—171.2	+0.332	0.59	+26°.3550
3	+ 72.8	76.8	.210	0.40	
5	147.6	+109.6	.193	0.44	
6	41.2	196.4	.265	0.39	
π	0.0	0.0		0.63	+27°.3391

No. 37. B.D. + 50°.2847–8. 16 Cygni. (19^h 39^m.1 ; + 50° 18′.)

Mag. 6.26–6.37. $\mu = \begin{cases} -\,0^s.0162\,;\, -\,0''.152. \\ -\,0^s.0138\,;\, -\,0''.156. \end{cases}$ Spectrum F.

The measures were in longitude. This is a star of the 61 Cyngi type. Other parallaxes published are:

Slocum and Mitchell,	Preceding,	+ 0″.043 ± 0″.008.
	Following,	+ 0″.028 ± 0″.009.
Adams,	Preceding,	+ 0″.063.
	Following,	+ 0″.040.
Jost,		+ 0″.15 ± 0″.031.

The same comparison field was used for both components.

TABLE AND SOLUTIONS FOR THE PRECEDING COMPONENT OF 16 CYGNI.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Sept. 19, 1915...	+0 6	M.	—4.09	—0.591	—0.094	1.0	+0.008	M.
June 5, 1916...	+0 16	S.	—1.49	+0.917	.093	.7	—0.004	M.
June 13, 1916...	—0 9	P.	1.41	.851	.079	.9	.019	M.
June 30, 1916...	0 44	P.	1.24	.663	.111	.8	+0.010	M.
July 7, 1916...	0 59	S.	1.17	.569	.103	1.0	.001	M.
Sept. 17, 1916...	+0 11	M.	—0.45	—0.573	.128	.8	+0.010	M.
Sept. 19, 1916...	0 7	M.	0.43	.600	.119	.8	.001	M.
Sept. 25, 1916...	—0 42	P.	0.37	.678	.103	.8	—0.016	M.
Sept. 28, 1916...	+0 12	M.	0.34	.715	.116	.7	.004	M.
Oct. 6, 1916...	—0 15	P.	0.26	.803	.123	.9	+0.002	M.
June 17, 1917...	—0 6	P.	+2.28	+0.815	.138	.6	+0.008	M.
June 17, 1917...	+0 8	P.	2.28	.815	.138	.9	.008	M.
Oct. 2, 1917...	+0 8	M.	+3.35	—0.757	.150	1.0	—0.003	M.
Oct. 3, 1917...	—0 10	P.	3.36	.768	.152	.8	.001	M.

Normal Equations:

$$+ 11.7000\,c - 0.5780\,\mu - 0.9367\,\pi = -1.3725.$$
$$+ 51.2834 \quad - 1.7842 \quad = -0.3968.$$
$$+ 6.1629 \quad = +0.1747.$$

Solution:

$$c = -\,0''.117.$$
$$\mu = -\,0''.041 \pm 0''.004.$$
$$\pi = +\,0''.037 \pm 0''.012.$$

p. e. unit weight, ± 0″.028.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	+ 69.2	+145.6	+0.296	0.50	
4	— 98.8	128.4	.121	0.47	
7	188.4	—184.8	.184	0.50	+49°.3079
10	+ 66.0	62.0	.399	0.60	+50°.2853
π'	0.0	0.0		0.71	+50°.2847

TABLE AND SOLUTIONS FOR THE FOLLOWING COMPONENT OF 16 CYGNI.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Sept. 19, 1915...	+0 6	M.	—4.09	—0.591	—0.104	1.0	+0.004	M.
June 5, 1916...	+0 16	S.	—1.49	+0.917	.116	.7	+0.001	M.
June 13, 1916...	—0 9	P.	1.41	.851	.109	.8	—0.007	M.
June 30, 1916...	0 44	P.	1.24	.663	.124	.8	+0.006	M.
July 7, 1916...	0 59	S.	1.17	.569	.114	.9	—0.005	M.
Sept. 17, 1916...	+0 11	M.	—0.45	—0.573	.128	.8	—0.002	M.
Sept. 19, 1916...	0 7	M.	0.43	.600	.133	.9	+0.003	M.
Sept. 25, 1916...	—0 42	P.	0.37	.678	.124	.8	—0.007	M.
Sept. 26, 1916...	0 37	P.	0.36	.691	.133	.8	+0.002	M.
Oct. 6, 1916...	0 15	P.	0.26	.803	.131	.9	—0.001	M.
June 17, 1917...	—0 6	P.	+2.28	+0.815	.153	.6	+0.007	M.
June 17, 1917...	+0 8	P.	2.28	.815	.148	.8	.002	M.
Oct. 2, 1917...	0 8	M.	+3.35	—0.757	.158	1.0	—0.003	M.
Oct. 3, 1917...	—0 10	P.	3.36	.768	.166	.5	+0.005	M.

Normal Equations:

$$+ 11.3000\,c — 1.6490\,\mu — 1.0421\,\pi = — 1.4710.$$
$$+ 47.0822 — 0.9547 = — 0.1719.$$
$$+ 5.8749 = + 0.1666.$$

Solution:

$$c = — 0''.131.$$
$$\mu = — 0''.038 \pm 0''.002.$$
$$\pi = + 0''.018 \pm 0''.006.$$

p. e. unit weight. $\pm 0''..014$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	+ 69.2	+145.6	+0.297	0.50	
4	— 98.8	128.4	.089	0.47	
7	188.4	—184.8	.182	0.50	+49°.3079
10	+ 66.0	62.0	.432	0.60	+50°.2853
π	+ 6.3	— 6.4		0.65	+50°.2848

No. 38.   B.D. $+ 34°.3727$.   OΣ 387.   (19^h $45^m.0$; $+ 35°$ $4'.$)
Mag. 6.9. $\mu = + 0^s.0068$; $+ 0''.084$.   Spectrum F_2.

This is a binary of long, uncertain period. The measures were made in longitude. Russell found for this star a hypothetical parallax of $0''.022$.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 7, 1914...	—0 37	P.	—4.13	—0.518	—0.090	.9	+0.008	M.
Sept. 8, 1914...	0 14	P.	4.12	.595	.090	.5	.008	M.
Sept. 9, 1914...	0 28	P.	4.11	.609	.079	.5	—0.003	M.
Sept. 10, 1914...	0 36	P.	4.10	.621	.072	.9	.010	M.
June 22, 1915...	+0 0	M.	—1.25	+0.632	.067	.6	+0.011	M.
Sept. 10, 1915...	+0 26	S.	—0.45	—0.619	.056	.8	+0.002	M.
Oct. 3, 1915...	0 9	S.	0.22	.871	.043	1.0	—0.010	M.
June 1, 1916...	+0 23	P.	+2.20	+0.858	.034	1.0	+0.004	M.
June 4, 1916...	0 0	P.	2.23	.829	.022	.7	—0.008	M.
June 13, 1916...	0 11	P.	2.32	.734	.015	.9	.014	M.
June 21, 1916...	0 5	S.	2.40	.634	.037	.5	+0.008	M.
June 22, 1916...	—0 36	P.	2.41	.620	.033	.7	.004	M.
Sept. 25, 1916...	+0 22	P.	+3.36	—0.803	.029	1.0	—0.003	M.
Sept. 28, 1916...	0 42	M.	3.39	.832	.035	.5	+0.009	M.

Normal Equations:

$$+ 10.5000\,c + 0.9390\,\mu - 1.0399\,\pi = - 0.5093.$$
$$+ 85.7079\ + 9.2814\ = + 0.6305.$$
$$+ 5.4813\ = + 0.1379.$$

Solution:

$$c = - 0''.049.$$
$$\mu = + 0''.035 \pm 0''.003.$$
$$\pi = + 0''.015 \pm 0''.012.$$

p. e. unit weight,, $\pm 0''.025$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	+168.2	— 18.9	+0.219	0.50	$+34°.3735$
9	—123.3	+ 43.6	.295	0.88	$+35°.3809$
11	98.3	— 79.7	.332	0.35	$+34°.3722$
15	+209.3	+115.9	.154	0.41	
π	0.0	0.0		0.82	$+34°.3727$

No. 39. B.D. + 6°.4357. β Aquilae = OΣ 532. (19^h 50^m.4; + 6° 9'.) Mag. 3.90. $\mu = + 0^s.0023; - 0''.483$.

Spectrum K.

The measures are in longitude. This star is B. G. C. 9724. The distance between the components is 12''.08 and their magnitudes are 3.4 and 11.3 respectively. The brighter component only was recorded. Burnham says, "But little change in either angle or distance but components have a large common proper motion."

Other published parallaxes are:

Mitchell, (Photographic), $+ 0''.066 \pm 0''.011$.

Adams, (Spectroscopic), $+ 0''.072$.

Russell, (Hypothetical), $+ 0''.053$.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 29, 1915...	+0 33	P.	−3.16	−0.904	+0.097	.5	−0.002	Be.
Oct. 10, 1915...	0 29	S.	3.05	.967	.106	.8	.012	Sm.
Oct. 12, 1915...	−0 4	P.	3.03	.974	.092	.9	+0.002	Sm.
Oct. 24, 1915...	+0 53	M.	2.91	.994	.099	.8	−0.006	Be.
June 1, 1916...	+0 39	P.	−0.70	+0.772	.112	.5	+0.001	Sm.
June 4, 1916...	0 16	P.	0.67	.738	.096	.6	.016	Sm.
June 5, 1916...	0 48	S.	0.66	.728	.116	1.0	−0.004	Be.
June 12, 1916...	0 34	S.	0.59	.640	.111	.7	.000	Be.
Sept. 10, 1916...	+0 44	P.	+0.31	−0.732	.088	.5	+0.001	Sm.
Oct. 6, 1916...	0 5	P.	0.57	.952	.079	.5	.006	Sm.
Oct. 7, 1916...	−0 18	Ma.	0.58	.956	.073	.9	.012	Be.
June 8, 1918...	+0 2	D.	+6.67	+0.697	.094	1.0	−0.002	Sm.
June 8, 1918...	0 18	D.	6.67	.697	.097	1.0	.005	Sm.

Normal Equations:

$$+ 9.7000\,c + 3.4020\,\mu - 1.2010\,\pi = + 0.9428.$$
$$+ 118.1568 + 15.8604 = + 0.2548.$$
$$+ 6.7576 = - 0.0648.$$

Solution:

$$c = + 0''.100.$$
$$\mu = - 0''.012 \pm 0''.003.$$
$$\pi = + 0''.067 \pm 0''.011.$$

p. e. unit weight, $\pm 0''.022$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
I	+ 98.0	−174.4	+0.265	0.87	+5°.4344
4	110.4	+144.0	.331	0.94	+6°.4362
5	−114.8	92.0	.243	0.46	
14	214.4	−147.6	.161	0.60	+5°.4332
π	0.0	0.0		0.77	+6°.4357

No. 40. B.D. + 20°.4452-3. Σ 2637 = Θ Sagittae. 20ʰ 5ᵐ.5;

$$+ 20° 37'.) \text{Mag. 7.0–7.8–8.3.} \mu = \begin{cases} + 0^s.0039; — 0''.096. \\ + 0^s.0036; — 0''.112. \\ — 0^s.0003; — 0''.010. \end{cases}$$

This star is number 9955 in B. G. C.   In the tables that follow I have used the designation given by Burnham.   No other parallax of this star has been published.   The measures were in longitude.   The same comparison field was used for each of the three components.

TABLE AND SOLUTIONS FOR Σ 2637 A.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution. m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 3, 1915...	+0 34	S.	−3.39	−0.517	−0.081	.7	−0.001	Be.
Sept. 7, 1915...	0 21	P.	3.35	.574	.082	.9	0.000	Be.
June 4, 1916...	+0 21	P.	−0.64	+0.832	.068	1.0	+0.004	Sm.
June 13, 1916...	0 14	P.	0.55	.737	.062	.5	−0.002	Be.
June 22, 1916...	−0 21	P.	0.46	.625	.060	.5	.004	Be.
Sept. 25, 1916...	+0 31	P.	+0.49	−0.800	.064	1.0	−0.001	Be.
Oct. 5, 1916...	0 37	P.	0.59	.889	.068	1.0	+0.003	Sm.
Oct. 12, 1916...	0 41	M.	0.66	.935	.065	.8	0.000	Sm.
June 7, 1918...	+0 2	Ma.	+6.69	+0.807	.028	.5	−0.002	Sm.

Normal Equations:

$$+ 6.8000\,c — 1.6290\,\mu — 1.3190\,\pi = — 0.4511.$$
$$+ 42.1021 + 3.4070 = + 0.3175.$$
$$+ 4.0341 = + 0.1173.$$

Solution:

$$c = — 0''.064.$$
$$\mu = + 0''.022 \pm 0''.001.$$
$$\pi = + 0''.019 \pm 0''.004.$$

p. e. unit weight, ± 0''.008.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+126.6	+ 39.1	+0.478	1.11	+20°.4460
4	—221.1	48.2	.336	0.81	+20°.4444
12	101.1	—103.1	.041	0.40	
14	+205.7	119.8	.145	0.45	
A	11.8	+ 13.2		1.16	+20°.4453

TABLE AND SOLUTIONS FOR Σ 2637 B.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas-ured by.
Sept. 3, 1915...	+0 34	S.	—4.53	—0.517	+0.002	.6	—0.008	Be.
Sept. 7, 1915...	0 21	P.	4.49	.574	—0.001	.9	.005	Be.
June 4, 1916...	+0 21	P.	1.78	+0.832	0.006	.9	+0.002	Sm.
June 13, 1916...	0 14	P.	1.69	.737	.008	1.0	0.000	Be.
June 22, 1916...	—0 21	P.	1.60	.625	.004	1.0	+0.005	Be.
Sept. 10, 1916...	+1 3	P.	0.80	—0.624	+0.011	.8	—0.001	Be.
Sept. 25, 1916...	0 31	P.	0.65	.800	.017	1.0	.006	Be.
Oct. 5, 1916...	0 37	P.	0.55	.889	.000	1.0	+0.011	Sm.
Oct. 12, 1916...	0 41	M.	0.48	.935	.008	.5	.003	Sm.
June 1, 1918...	0 0	D.	+5.49	+0.865	+0.040	1.0	0.000	Sm.
June 7, 1918...	—0 18	Ma.	5.55	.807	.035	.5	+0.005	Sm.
June 7, 1918...	+0 2	Ma.	5.55	.807	.047	.9	— .007	Sm.

Normal Equations:

$$+ 10.1000\,c - 0.4710\,\mu + 0.6231\,\pi = + 0.1473.$$
$$+ 113.3401 + 12.7983 = + 0.5006.$$
$$+ 5.8526 = + 0.0728.$$

Solution:

$$c = + 0''.015.$$
$$\mu = + 0''.020 \pm 0''.002.$$
$$\pi = + 0''.007 \pm 0''.009.$$

p. e. unit weight, $\pm 0''.018$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+126.6	+ 39.1	+0.485	1.11	+20°.4460
4	—221.1	48.2	.343	0.81	+20°.4444
12	101.1	—103.1	.034	0.40	
14	+205.7	119.8	.138	0.45	
B	10.5	+ 15.4		0.53	

TABLE AND SOLUTIONS FOR Σ 2637 C.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 3. 1915...	+0 34	S.	−4.53	−0.517	−0.104	1.0	−0.001	Be.
Sept. 7, 1915...	0 21	P.	4.49	.574	.109	1.0	+0.004	Be.
June 4, 1916...	+0 21	P.	−1.78	+0.832	.106	1.0	+0.007	Sm.
June 13, 1916...	0 14	P.	1.69	.737	.091	.9	−0.009	Be.
June 22, 1916...	−0 21	P.	1.60	.625	.100	1.0	0.000	Be.
Sept. 10, 1916...	+1 3	P.	−0.80	−0.624	.095	.8	−0.011	Be.
Sept. 25, 1916...	0 31	P.	0.65	0.800	.102	.8	.005	Be.
Oct. 5, 1916...	0 37	P.	0.55	.889	.116	1.0	+0.008	Sm.
Oct. 12, 1916...	0 41	M.	0.48	.935	.109	1.0	.001	Sm.
June 1, 1918...	0 0	D.	+5.49	+0.865	.116	.7	+0.014	Sm.
June 7, 1918...	−0 18	Ma.	5.55	.807	.094	.6	−0.008	Sm.
June 7, 1918...	+0 2	Ma.	5.55	.807	.096	.6	.006	Sm.

Normal Equations:

$$+ 10.4000\,c - 5.6080\,\mu - 0.3600\,\pi = - 1.0787.$$
$$+ 108.4239 + 11.7693 = + 0.5991.$$
$$+ 5.9618 = + 0.0608.$$

Solution:

$$c = - 0''.104.$$
$$\mu = - 0''.002 \pm 0''.003.$$
$$\pi = + 0''.022 \pm 0''.011.$$

p. e. unit weight, ± 0''.024.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+126.6	+ 39.1	+0.402	1.11	+20°.4460
4	−221.1	48.2	.328	0.81	+20°.4444
12	101.1	−103.1	.110	0.40	
14	+205.7	119.8	.160	0.45	
π	0.0	0.0		0.91	+20°.4452

No. 41. B.D.+ 43°.3513. OΣ 400. (20ʰ 6ᵐ.9; = 43° 39′.)
Mag. 7.5–8.5.

The measures are in longitude. This is a binary with a period of 74.5 years (Burnham). The components are separated by 0''.31. The combined image, which is sensibly round, was bisected in the measuring. Russell finds a hypothetical parallax of 0''.021.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 21, 1914...	—0 13	M.	—2.97	—0.580	—0.109	1.0	+0.003	Be.
Sept. 22, 1914...	0 3	M.	2.96	.594	.105	.8	—0.001	Be.
Oct. 2, 1914...	+0 4	M.	2.86	.721	.109	1.0	+0.001	Be.
June 23, 1915...	—0 3	Ma.	—0.22	+0.790	.093	1.0	0.000	Be.
June 24, 1915...	+0 2	M.	0.21	.780	.087	.7	—0.006	Be.
June 27, 1915...	0 7	M.	0.18	.745	.095	.5	+0.002	Be.
Sept. 15, 1915...	—0 40	S.	+0.62	—0.491	.104	.9	0.000	Be.
Sept. 25, 1915...	0 16	Ma.	0.72	.631	.113	.7	+0.007	Be.
Oct. 23, 1915...	+0 8	P.	1.00	.913	.102	1.0	—0.006	Be.
June 30, 1916...	—0 30	P.	+3.51	+0.701	.093	1.0	0.000	Be.
July 7, 1916...	0 33	S.	3.58	.611	.096	1.0	+0.004	Be.

Normal Equations:

$$+9.600\,c + 4.970\,\mu - 0.552\,\pi = -0.967.$$
$$+50.951 + 7.979 = +0.038.$$
$$+4.660 = +0.100.$$

Solution:

$$c = -0''.100.$$
$$\mu = +0''.001 \pm 0''.002.$$
$$\pi = +0''.043 \pm 0''.007.$$

p. e. unit weight, $\pm 0''.012$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	—200.0	+140.8	+0.152	0.61	+43°.3506
2	124.0	— 47.2	.354	0.54	+43°.3509
5	+ 81.6	+ 33.6	.215	0.63	+43°.3517
9	195.2	— 50.4	.279	0.48	+43°.3521
π	0.0	0.0		0.82	+43°.3513

No. 42. B.D. + 15°.4255. γ Delphini. (20^h 42^m.0; + 15° 46'.)

Mag. A. 4.49. $\left\{ \mu = \right.$ A. — 0^s.0023; — 0''.204. Spectrum G$_5$.

B. 5.47. B. — 0^s.0014; — 0''.194.

This star was measured in right ascension. The components have a common proper motion and some relative motion. Other published parallaxes are by

Russell, (Hypothetical),   + 0″.045.

Mitchell, (Photogrpahic), A. + 0″.071 ± 0″.009.

B. + 0″.063 ± 0″.009.

Adams, (Spectroscopic),   + 0″.022.

The same comparison field was used for both A and B.

Table and Solutions for A.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas-ured by.
Sept. 13, 1915...	—0 12	S.	—4.59	—0.65	—0.028	.8	+0.013	M.
Sept. 14, 1915...	+0 3	P.	4.58	.66	.013	1.0	—0.002	M.
Nov. 5, 1915...	1 10	M.	4.06	.95	.015	.5	.001	M.
June 13, 1916...	+0 4	P.	—1.85	+0.70	.023	.5	+0.001	M.
June 21, 1916...	0 15	S.	1.77	.60	.022	.9	0.000	M.
June 30, 1916...	—0 17	Ma.	1.68	.48	.019	.8	—0.003	M.
July 7, 1916...	0 20	W.	1.61	.37	.011	.7	.011	M.
Sept. 25, 1916...	+0 27	P.	—0.81	—0.78	.022	1.0	+0.001	M.
Oct. 6, 1916...	—0 11	P.	0.70	.87	.023	1.0	.002	M.
Oct. 26, 1916...	+0 25	M.	0.50	.96	.029	.5	.008	M.
June 7, 1918...	—0 1	Ma.	+5.39	+0.77	.032	.5	—0.001	M.
June 15, 1918...	0 28	D.	5.47	.68	.038	.8	+0.005	M.
July 1, 1918...	1 2	P.	5.63	.47	.023	.5	—0.010	M.
July 2, 1918...	0 33	D.	5.64	.46	.031	.9	.002	M.

Normal Equations:

$$+ 10.4000\,c - 2.0690\,\mu - 0.6740\,\pi = -0.2424.$$
$$+ 138.8869 + 14.8623 = -0.1464.$$
$$+ 4.8674 = 0.0000.$$

Solution:

$$c = -0''.024.$$
$$\mu = -0''.007 \pm 0''.002.$$
$$\pi = +0''.007 \pm 0''.010.$$

p. e. unit weight, ± 0″.018.

Comparison Stars.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+208.6	— 12.2	+0.279	0.90	+15°.4258
3	—127.2	22.7	.478	0.80	+15°.4248
6	268.3	+113.5	.082	0.49	+15°.4244
9	+153.0	30.6	.161	0.62	
A	0.0	0.0		1.06	+15°.4255

TABLE AND SOLUTIONS FOR B.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Sept. 13, 1915...	—0 12	S.	—4.47	—0.65	+0.107	.5	+0.018	M.
Sept. 14, 1915...	+0 3	P.	4.46	.66	.133	.7	—0.008	M.
Nov. 5, 1915...	1 10	M.	3.94	.95	.117	.8	+0.009	M.
June 13, 1916...	+0 4	P.	1.73	+0.70	.109	.5	+0.013	M.
June 21, 1916...	0 15	S.	1.65	.60	.126	.6	—0.004	M.
June 22, 1916...	—0 25	P.	1.64	.58	.126	.5	.004	M.
June 30, 1916...	0 17	Ma.	1.56	.48	.119	.6	+0.003	M.
July 7, 1916...	0 20	W.	1.49	.37	.134	1.0	—0.012	M.
Sept. 25, 1916...	+0 27	P.	0.69	—0.78	.118	.5	+0.006	M.
Oct. 6, 1916...	—0 6	P.	0.58	.87	.136	.9	—0.012	M.
Oct. 26, 1916...	+0 30	M.	0.38	.96	.124	.5	.000	M.
June 7, 1918...	—0 1	Ma.	+5.51	+0.77	.127	.5	—0.008	M.
June 15, 1918...	0 28	D.	5.59	.68	.110	1.0	+0.009	M.
July 1, 1918...	1 2	P.	5.75	.47	.122	.5	—0.002	M.
July 2, 1918...	0 33	D.	5.76	.46	.119	1.0	+0.001	M.

Normal Equations:

$$+ 10.1000\,c + 2.3130\,\mu + 0.2180\,\pi = + 1.2356.$$
$$+ 141.2385 + 14.6610 = + 0.2092.$$
$$+ 4.6696 = + 0.0138.$$

Solution:

$$c = + 0''.122.$$
$$\mu = - 0''.002 \pm 0''.003.$$
$$\pi = - 0''.008 \pm 0''.015.$$

p. e. unit weight, $\pm 0''.026$.

COMPARISON STARS.

2	+208.6	— 12.2	+0.276	0.90	+15°.4258
3	—127.2	22.7	.483	0.80	+15°.4248
6	268.3	+113.5	.084	0.49	+15°.4244
9	+153.0	30.6	.157	0.62	
B	— 2.3	+ 0.0		0.88	

No. 43.   B.D. + 3°.4473.   Σ 2737 = ε Equulei.   (20^h 54^m.1; + 3° 55'.)   Mag. 5.29. μ = — 0^s.0084; — 0″.144.

Spectrum F$_5$.

This is a triple system. The three components, called by Burnham, A (mag. 5.1), B (mag. 6.2), and C (mag. 7.1), have a common proper motion. A and B, separated by 0″.62, form a binary of uncertain period. The measures were made by bisecting the combined image of these two components, which is sensibly round. The measures are in longitude. Other published parallaxes are:

Russell, (Hypothetical),   + 0″.022.
Mitchell, (Photographic), + 0″.043 ± 0″.010.
Adams, (Spectroscopic),   + 0″.038.

Mitchell found for C a parallax of 0″.002 ± 0″.012. We did not measure C because its images on our plates were very faint.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Oct. 30, 1915...	+0 13	Ma.	—3.55	—0.974	+0.132	.8	—0.010	Sm.
Nov. 7, 1915...	0 44	S.	3.47	.989	.113	1.0	+0.008	Be.
June 13, 1916...	+0 20	P.	—1.28	+0.825	.100	.5	+0.010	Sm.
June 22, 1916...	—0 10	P.	1.19	.727	.106	.5	.003	Sm.
June 30, 1916...	+0 20	Ma.	1.11	.627	.110	.7	—0.002	Be.
July 4, 1916...	0 50	M.	1.07	.576	.116	.8	.009	Be.
Sept. 28, 1916...	+0 30	M.	—0.21	—0.746	.096	.5	—0.001	Be.
Oct. 6, 1916...	0 19	P.	0.13	.829	.103	.6	.009	Sm.
Oct. 7, 1916...	0 28	Ma.	0.12	.838	.095	.5	.001	Be.
Oct. 8, 1916...	0 0	M.	0.11	.847	.082	.8	+0.012	Sm.
June 8, 1918...	—0 7	D.	+5.97	+0.875	.044	1.0	+0.007	Sm.
July 7, 1918...	0 46	P.	6.26	.536	.054	1.0	—0.007	Sm.

Normal Equations:

$$+ 8.7000\,c + 2.7210\,\mu — 0.6485\,\pi = + 0.8123.$$
$$+ 100.3061 + 13.1041 = — 0.5091.$$
$$+ 5.5508 = — 0.1481.$$

Solution: c = + 0″.096.
$$\mu = — 0″.038 ± 0″.003.$$
$$\pi = + 0″.018 ± 0″.012.$$

p. e. unit weight, ± 0″.024.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	+223.9	− 75.0	+0.332	0.45	
6	12.1	62.0	.059	0.54	
10	− 83.9	21.0	.128	0.37	
12	134.4	+ 64.7	.481	0.47	+3°.4469
π	0.0	0.0		0.66	+3°.4473

No. 44. B.D. + 45°.3558. 71 g Cygni. (21^h 25^m.8; + 46° 6'.)
Mag. 5.35. $\mu = -$ 0^s.0044; + 0''.104. Spectrum K.

The measures were in right ascension. Other published parallaxes are:

Abetti, (Transits), + 0''.056 ± 0''.043.

Schlesinger, (Photographic), + 0''.040 ± 0''.043.

Adams, (Spectroscopic), + 0''.014.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Measured by.
Sept. 22, 1914...	−0 29	M.	−2.67	−0.61	−0.150	.8	−0.003	S.
Nov. 2, 1914...	+0 6	P.	2.26	.93	.155	.8	+0.002	S.
June 22, 1915...	0 5	M.	+0.06	+0.72	.135	8.	−0.001	S.
June 24, 1915...	0 2	M.	0.08	.70	.125	1.0	.011	S.
June 28, 1915...	−0 1	Ma.	0.12	.66	.138	.9	+0.002	S.
July 5, 1915...	0 4	Ma.	0.19	.56	.147	.8	.011	S.
July 6, 1915...	0 0	M.	0.20	.55	.135	1.0	−0.001	S.
July 8, 1915...	−0 3	M.	0.22	.52	.135	.9	.001	S.
Sept. 10, 1915...	−0 18	S.	+0.86	−0.41	.142	.7	+0.003	S.
Nov. 17, 1915...	0 0	P.	1.54	.94	.138	.8	−0.002	S.
Nov. 27, 1915...	+0 19	M.	1.64	.92	.138	.6	.001	S.

Normal Equations:

$$+ 9.100 c - 0.340 \mu + 0.513 \pi = - 1.268.$$
$$+ 13.953 + 1.134 = + 0.102.$$
$$+ 4.415 = - 0.042.$$

Solution:

$$c = - 0''.140.$$
$$\mu = + 0''.016 \pm 0''.005.$$
$$\pi = + 0''.027 \pm 0''.008.$$

p. e. unit weight, ± 0''.018.

<div align="center">COMPARISON STARS.</div>

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
3	— 55.2	—139.2	+0.223	0.54	+46°.3331
4	127.1	83.0	.391	0.55	+46°.3325
10	+182.2	+222.2	.386	0.48	+45°.3567
π	8.2	22.1		0.89	+45°.3558

No. 45.   B.D. + 45°.3562.   (21^{h} 26^{m}.1 + 46° 7'.2.)   Mag. 9.5.

The measures were in right ascension. No other parallax has been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p.	Res., v.	Meas- ured by.
Sept. 22, 1914...	—0 29	M.	—2.66	—0.61	—0.146	.7	+0.008	S.
Nov. 2, 1914...	+0 6	P.	2.25	.93	.130	.8	—0.007	S.
June 22, 1915...	+0 5	M.	+0.07	+0.72	.137	.8	+0.002	S.
June 28, 1915...	—0 1	Ma.	0.13	.66	.130	1.0	—0.005	S.
July 5, 1915...	0 4	Ma.	0.20	.56	.133	1.0	.002	S.
July 6, 1915...	0 0	M.	0.21	.55	.135	.9	0.000	S.
July 8, 1915...	—0 3	M.	0.23	.52	.134	1.0	—0.001	S.
Sept. 10, 1915...	—0 18	S.	+0.87	—0.41	.123	.8	—0.008	S.
Nov. 17, 1915...	0 0	P.	1.55	.94	.132	.7	+0.002	S.
Nov. 27, 1915...	+0 19	M.	1.65	.92	.137	.6	.007	S.

Normal Equations:

$$+ 8.300\, c — 0.086\, \mu + 0.102\, \pi = — 1.111.$$
$$+ 13.077 + 1.055 = + 0.034.$$
$$+ 3.920 = — 0.017.$$

Solution:

$$c = — 0''.134.$$
$$\mu = + 0''.009 \pm 0''.005.$$
$$\pi = — 0''.006 \pm 0''.009.$$

p. e. unit weight, ± 0''.017.

<div align="center">COMPARISON STARS.</div>

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
4	—157.6	—209.9	+0.756	0.55	+46°.3325
8	24.8	+ 65.7	—0.636	0.50	
9	+ 30.6	48.9	+0.072	0.42	+45°.3563
10	151.7	95.3	.808	0.48	+45°.3567
π	21.3	—120.1		0.54	+45°.3562

No. 46. B.D. + 45°.3566. (21^h 26^m.8; + 46° 5'.7.) Mag. 8.2.

The measures are in right ascension. No other parallax has been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt,, p,	Res., v.	Meas- ured by.
Sept. 22, 1914...	—0 29	M.	—2.65	—0.61	+0.132	.8	+0.006	S.
Nov. 2, 1914...	+0 6	P.	2.24	.92	.144	.7	—0.005	S.
June 22, 1915...	+0 5	M.	+0.08	+0.72	.145	.8	—0.002	S.
June 24, 1915...	0 2	M.	0.10	.70	.146	1.0	.003	S.
June 28, 1915...	—0 1	Ma.	0.14	.66	.158	.8	.015	S.
July 5, 1915...	0 4	Ma.	0.21	.56	.131	.8	+0.012	S.
July 8, 1915...	0 3	M.	0.24	.52	.137	.9	.006	S.
Sept. 10, 1915...	—0 18	S.	+0.88	—0.41	.142	.8	+0.003	S.
Nov. 17, 1915...	0 0	P.	1.56	.94	.139	.8	.007	S.
Nov. 27, 1915...	+0 19	M.	1.66	.92	.158	.5	—0.012	S.

Normal Equations:

$$+ 7.900\,c — 0.246\,\mu + 0.048\,\pi = + 1.127.$$
$$+ 13.192\ \ +0.907\ \ \ = —0.009.$$
$$+ 3.902\ \ \ = + 0.010.$$

Solution:

$$c = + 0''.143.$$
$$\mu = + 0''.009 \pm 0''.007.$$
$$\pi = + 0''.002 \pm 0''.014.$$

p. e. unit weight, ± 0''.027.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	+112.5	+135.4	+0.323	0.54	+46°.3565
3	— 92.7	—184.4	1.259	0.54	+46°.3331
4	164.5	128.1	—0.885	0.55	+46°.3325
10	+144.8	+177.1	+0.303	0.48	+45°.3567
π	109.3	— 21.1		1.00	+45°.3566

No. 47.   B.D. + 29°.4550.   Lalande 42883-5.   (21^h 54^m.2; + 29° 21'.)   Mag. 7.3. $\mu = -$ 0^s.0295; $-$ 0″.378.

The measures are in right ascension.   Other published parallaxes are:

Flint,   + 0″.080 ± 0″.027.
Gill,   + 0″.274 ± 0″.017.
Elkin,   + 0″.124 ± 0″019.
Chase,   + 0″.020 ± 0″.043.
Adams,   + 0″.066.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt,, p,	Res., v.	Meas- ured by.
Oct. 11, 1915...	—0 23	P.	—3.20	—0.74	+0.021	.7	—0.004	Sm.
Oct. 21, 1915...	+0 2	M.	3.10	.82	.016	.8	.002	Sm.
Oct. 30, 1915...	0 17	Ma.	3.01	.87	.016	1.0	.003	Sm.
June 30, 1916...	—0 2	Ma.	—5.57	+0.70	—0.017	.7	—0.008	Sm.
July 7, 1916...	+0 18	Ma.	0.50	.62	.035	.8	+0.009	Sm.
July 11, 1916...	0 48	M.	0.46	.57	.028	.9	0.000	Sm.
July 28, 1916...		Ma.	0.29	.34	.044	.6	+0.011	Sm.
Oct. 7, 1916...	+0 16	Ma.	+0.42	—0.70	—0.046	.6	—0.008	Sm.
Oct. 26, 1916...	0 52	M.	0.61	.86	.066	.8	+0.007	Sm.
Nov. 2, 1916...	0 30	M.	0.68	.90	.065	.8	.004	Sm.
June 25, 1917...	—0 9	M.	+3.03	+0.75	—0.100	.7	+0.005	Sm.
June 30, 1917...	0 52	P.	3.08	.71	.084	.8	—0.013	Sm.
July 27, 1917...	+0 8	Ma.	3.35	.35	.103	.5	.001	Sm.

Normal Equations:

$$+ 9.7000\, c - 1.5730\, \mu - 0.9010\, \pi = - 0.3691.$$
$$+ 44.9849 \quad + 8.3282 \quad = - 0.7656.$$
$$+ 5.0824 \quad = - 0.0910.$$

Solution: c $= -$ 0″.041.

$$\mu = - 0″.093 \pm 0″.004.$$
$$\pi = + 0″.034 \pm 0″.011.$$

p. e. unit weight, ± 0″.021.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	—152.8	— 74.0	+0.344	0.53	
3	140.0	+123.2	.204	0.37	
6	+142.2	140.0	.155	0.74	+29°.4558
9	198.8	— 72.8	.297	0.49	
π	0.0	0.0		0.70	+29°.4550

No. 48.   B.D. $+ 69°.1228$. Σ 2883.   ($22^h\ 8^m.4$; $+ 69°\ 38'$.)
Mag. 5.54. $\mu = - 0^s.0106$; $+ 0''.018$.   Spectrum F.

The measures are in right ascension.   The brighter component only was measured.   No other parallax has been published.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution. m.	Wt., p.	Res., v.	Measured by.
Nov. 9, 1915...	$+$0 32	Ma.	$-$3.33	$-$0.91	$-$0.073	.9	$-$0.006	Sm.
Nov. 21, 1915...	0 5	M.	3.21	.92	.075	1.0	.005	Sm.
Nov. 26, 1915...	0 30	P.	3.16	.93	.087	.9	$+$0.006	Sm.
June 30, 1916...	$+$0 19	Ma.	$-$0.99	$+$0.73	.077	1.0	$+$0.003	Be.
July 7, 1916...	0 28	Ma.	0.92	.67	.077	.6	.002	Be. Sm.
Oct. 11, 1916...	$-$0 16	P.	$+$0.04	$-$0.70	.113	.5	$+$0.006	Be.
Nov. 7, 1916...	$+$0 19	M.	0.31	.90	.117	1.0	.004	Sm.
June 30, 1917...	$-$0 29	P.	$+$2.66	$+$0.73	.114	.6	$+$0.007	Sm.
June 30, 1917...	0 17	P.	2.66	.73	.101	.9	$-$0.006	Sm.
July 30, 1917...	0 58	P.	2.96	.36	.113	.9	.003	Sm.
July 30, 1917...	0 44	P.	2.96	.36	.114	.7	.002	Sm.

Normal Equations:

$$+ 9.0000\,c - 1.5370\,\mu - 1.0230\,\pi = - 0.8565.$$
$$+ 55.4880\ \ \ \ \ + 11.5575\ \ \ \ \ \ = - 0.1738.$$
$$+ 5.2340\ \ \ \ \ = + 0.0777.$$

Solution:

$$c = - 0''.095.$$
$$\mu = - 0''.043 \pm 0''.003.$$
$$\pi = + 0''.078 \pm 0''.010.$$

p. e. unit weight, $\pm 0''.016$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	$+$178.0	$+$ 91.2	$+$0.262	0.64	$+69°.1231$
6	114.0	$-$182.4	.277	0.77	$+69°.1230$
10	$-$104.8	$+$ 37.6	.239	0.62	$+69°.1227$
12	238.4	81.2	.222	0.86	$+69°.1219$
π	0.0	0.0		0.64	$+69°.1228$

No. 49.   B.D. + 29°.4741.   η Pegasi.   (22^h 38^m.3; + 29° 42'.)
Mag. 3.10. μ = + 0^s.0008; — 0''.035.   Spectrum G.

The measures are in longitude.   This star is a spectroscopic binary.   Other published parallaxes are:

Flint,   — 0''.037 ± 0''.027.
Schlesinger,   — 0''.002 ± 0''.013.
Adams,   + 0''.042.

Date.	Hour Angle. h. m.	Obs.	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt., p,	Res., v.	Meas-ured by.
Oct. 25, 1915...	+0 5	P.	—3.44	—0.598	+0.187	.5	0.000	Sm.
Dec. 1, 1915...	0 22	P.	3.07	.949	.192	1.0	—0.004	Be.
Dec. 14, 1915...	0 54	M.	2.94	.983	.184	1.0	+0.004	Be.
Aug. 6, 1916...	—1 0	M.	—0.58	+0.651	.202	1.0	—0.012	Be. Sm.
Aug. 13, 1916...	+0 24	P.	0.51	.555	.184	.8	+0.006	Be.
Aug. 15, 1916...	0 29	P.	0.49	.524	.178	.8	.012	Sm.
Nov. 7, 1916...	0 36	M.	+0.35	—0.768	.191	.8	+0.001	Be. Sm.
Dec. 17, 1916...	1 11	M.	0.75	.984	.186	1.0	.007	Be.
Dec. 19, 1916...	1 11	M.	0.77	.982	.202	.9	—0.009	Sm.
July 30, 1917...	—0 35	P.	+3.00	+0.740	.199	.6	—0.005	Sm.
Aug. 5, 1917...	0 42	P.	3.06	.666	.188	.9	+0.006	Sm.
Aug. 10, 1917...	1 21	P.	3.11	.599	.201	.5	—0.007	Sm.

Normal Equations:

$$+ 9.8000\,c — 1.2780\,\mu — 1.8561\,\pi = + 1.8708.$$
$$+ 44.5793 \quad + 8.4866 \quad = — 0.1926.$$
$$+ 6.1507 \quad = — 0.3488.$$

Solution: c = + 0''.191
$$\mu = + 0''.006 ± 0''.004.$$
$$\pi = — 0''.004 ± 0''.012.$$

p. e. unit weight, ± 0''.024.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
2	+188.4	+ 25.2	+0.359	0.63	
6	—231.2	186.8	.207	0.59	
11	244.4	— 61.6	.157	0.48	
22	+ 65.6	139.2	.277	0.39	
π	0.0	0.0		1.10	+29°.4741

No. 50. B.D. + 19°.5094. Σ 3007. (23ʰ 17ᵐ.8; + 20° 1′.)
Mag. 6.9. $\mu = + 0^{s}.0226; - 0''.019$.

Σ 3007 is a double star, whose components have a common proper motion. The brighter component only was measured. The measures are in longitude. No other parallaxes have been published for this star.

Date.	Hour Angle. h. m.	Obs,,	Time in 100 Days, T.	Parallax Factor, P.	Solution, m.	Wt,, p,	Res., v.	Meas- ured by.
Nov. 26, 1915...	+0 54	P.	−3.42	−0.894	+0.048	.5	+0.002	Sm.
Dec. 26, 1915...	1 38	M.	3.12	.979	.059	.6	−0.006	Be.
Aug. 13, 1916...	+0 22	P.	−0.81	+0.615	.114	.9	−0.004	Be. Sm.
Aug. 17, 1916...	0 37	P.	0.77	.558	.108	.5	+0.002	Be.
Aug. 19, 1916...	0 13	P.	0.75	.530	.104	.7	.005	Sm.
Nov. 8, 1916...	+0 4	P.	+0.06	−0.731	.093	.8	+0.012	Be. Sm.
Dec. 10, 1916...	0 51	M.	0.38	.970	.116 .116	.7	−0.009	Be. Sm.
Aug. 5, 1917...	−0 38	P.	+2.76	+0.721	.169	.9	−0.003	Be.
Aug. 10, 1917...	0 5	Ma.	2.81	.668	.160	.6	+0.006	Sm.
Aug. 11, 1917...	+0 10	M.	2.82	.644	.168	1.0	−0.002	Sm.

Normal Equations:

$$+ 7.2000\,c + 2.0830\,\mu + 0.5990\,\pi = + 0.8605.$$
$$+ 32.6194 + 6.8602 = + 0.8268.$$
$$+ 3.9039 = + 0.2245.$$

Solution:

$$c = + 0''.114.$$
$$\mu = + 0''.072 \pm 0''.004.$$
$$\pi = + 0''.061 \pm 0''.012.$$

p. e. unit weight $\pm 0''.019$.

COMPARISON STARS.

No.	X.	Y.	Dependence.	Diameter.	B. D. No.
1	+237.2	− 97.0	+0.280	0.44	
10	−148.0	+180.0	.334	0.41	
18	50.3	− 33.5	.231	0.30	
20	34.6	162.2	.155	0.36	
π	0.0	0.0		0.64	+19°.5094

Summary of Results. (Second List of Fifty Stars.)

No.	B.D. Number.	Star.	R.A., 1900. h. m.	Declination, 1900.	Magnitude.	Spectrum.	Relative Parallax.	No. of Plates.	Coördinates.
1	− 4°.62	Ho. 212 = 13 Ceti	0 31.1	− 4° 9'	5.24	F	+ 0".048 ± 0".010	15	R.A.
2	+ 37 .175	μ Andromedae*	51.2	+ 37 57	3.94	A_2	+ .032 .013	12	Long.
3	+ 46 .243	OΣ 21*	57.3	+ 46 50	6.36	F	+ .007 .008	11	Long.
4	+ 54 .236	θ Cassiopeia*	1 5.0	+ 54 37	4.52	A_5	− .003 .003	12	Long.
5	+ 49 .444	φ Persei*	37.4	+ 50 11	4.19	B_p	+ .021 .010	12	R.A.
6	+ 1 .347	Σ 186*	50.7	+ 1 21	6.18	F	+ .042 .006	11	Long.
7	+ 41 .395	γ¹ (A) Andromedae*	57.8	+ 41 51	2.28	K_p	+ .021 .014	15	Long.
		γ² (BC) Andromedae*			5.08		+ .005 .008	14	Long.
8	+ 67 .191	Bradley 3227*	2 7.5	+ 67 13	7.8	K	+ .052 .010	18	Long.
9	+ 24 .375	Bradley 360*	31.2	+ 24 12.8	7.3	F	+ .030 .005	13	Long.
	+ 24 .376	Bradley 361			6.9	F_5	+ .034 .004	13	Long.
10	+ 49 .857	ι Persei	3 2.0	+ 49 14	4.1	G	+ .120 .012	12	Long.
11	+ 0 .542	Σ 367*	9.0	+ 0 21.7	8.0		+ .026 .008	11	Long.
12	+ 31 .642	o Persei = β 535*	38.0	+ 31 58	4.0	B_1	+ .030 .006	12	Long.
13	+ 34 .796	Greenwich₀₀ 284*	56.5	+ 35 2	8.5		+ .072 .005	12	Long.
14	+ 53 .794	Σ 566	4 32.0	+ 53 16.6	5.44	A	+ .021 .007	16	Long.
15	+ 53 .3796	Δ 4	32.5	+ 53 17	8.8		+ .004 .007	16	Long.
		Δ 4'			9.8		− .003 .009	16	Long.
16	+ 45 .992	Groombridge 884*	44.4	+ 45 41	6.5	K	+ .072 .012	13	Long.
17	− 5 .1123	Weisse 4ʰ.1189	55.9	− 5 52	6.5	F	+ .103 .012	12	Long.
18	+ 8 .866	OΣ 98 = 14 Orionis	5 2.5	+ 8 22	6.0	F	+ .016 .012	12	Long.
19	+ 39 .1248	λ Aurigae = Σ 3	12.1	+ 40 1	4.85	G	+ .070 .007	12	Long.
20	− 3 .1123	Weisse I 5ʰ.592*	26.4	− 3 42	8.7	M_a	+ .146 .014	13	Long.
21	− 13 .2267	β 101 = 9 Argus*	7 47.1	− 13 38	5.6	F_s	+ .121 .009	13	R.A.
22	+ 27 .1589	χ Cancri*	8 14	+ 27 33	5.16	F	+ .060 .006	13	R.A.
23	+ 42 .1922	Σ 1263* = Lalande 17161	38.6	+ 42 3	8.5		+ .104 .011	13	R.A.
24	+ 42 .2214	OΣ 234*	11 26.2	+ 41 52	7.0		+ .038 .011	15	R.A.
25	+ 28 .2106	Bradley 1646	12 14.5	+ 28 43	6.3	F	+ .048 0.11	13	R.A.
26	+ 26 .2345	Σ 1639	19.4	+ 26 8	6.7	A_5	− .028 .014	14	R.A.

SUMMARY OF RESULTS. (SECOND LIST OF FIFTY STARS.)—Concluded.

No.	B.D. Number.	Star.	R.A. 1900 h.	R.A. 1900 m.	Declination, 1900	Magnitude.	Spectrum.	Relative Parallax.	No. of Plates.	Coördinates.
27	+10°.2466	33 Virginis = Br 1706		41.3	+10° 6'	5.86	K	$- 0''.018 \pm 0''.012$	20	Long.
28	+17 .261	β 800	13	11.9	+17 33	7.0		+ .070 .010	12	R.A.
29	+35 .2462	O2 269*		28.3	+35 25	7.2		+ .067 .012	13	R.A.
30	+30 .2653	η Coronae Borealis*	15	19.1	+30 39	5.58	G	+ .085 .008	13	R.A.
31	+2 .3118	λ Ophiuchi*	16	25.9	+2 12	3.85	A	- .0037 .005	12	Long.
32	+32 .2896	72 w Herculis	17	16.9	+32 36	5.36	G	+ .064 .009	15	Long.
33	-0 .33	Σ 2173*		25.2	-0 59	5.34	G	+ .051 .009	13	Long.
34	+30 .3128	99 b Herculis*	18	3.2	+30 33	5.21	F8	+ .043 .010	13	Long.
35	+38 .3466	Σ 2481 (π)*	19	7.7	+38 36	8.0		+ .016 .009	12	Long.
		Secchi 2 (π')*				8.0		- .011 .009	12	Long.
36	+27 .3391	Σ 2525*		22.5	+27 7	7.5	G	+ .013 .013	12	Long.
37	+50 .2847	16 Cygni Pre. Comp.*		39.1	+50 18	6.26	F	+ .037 .012	14	Long.
	+50 .2848	16 Cygni Foll. Comp.*				6.37		+ .018 .006	14	Long.
38	+34 .3727	O2 387*			35 4	6.9	F2	+ .015 .012	14	Long.
39	+6 .4357	β Aquilae = O2 532*		50.4	+6 9	3.90	K	+ .067 .011	13	Long.
40	+20 .4453	Σ 2637 = θ Sagittae A*	20	5.5	+20 37	7.0		+ .019 .004	9	Long.
	+20 .4453	Σ 2637 B*				8.3		+ .007 .009	12	Long.
	+20 .4452	Σ 2637 C*				7.8		+ .022 .011	12	Long.
41	+43 .3513	O2 400*		6.9	+43 39	7.5		+ .043 .007	11	Long.
42	+15 .4255	γ Delphini A	20	42.0	+15 46	4.49	G5	+ .007 .010	14	R.A.
		γ Delphini B				5.47		- .008 .015	15	R.A.
43	+3 .4473	Σ 2737 = ε Equulei*		54.1	+3 55	5.29	F5	+ .018 .012	12	Long.
44	+45 .3558	71g Cygni*	21	25.8	+46 6	5.35	K	+ .027 .008	11	R.A.
45	+45 .3562			26.1	+46 7.2	9.5		- .006 .009	10	R.A.
46	+45 .3566			26.8	+46 5.7	8.2		+ .002 .014	10	R.A.
47	+29 .455	Lalande 42883 — 5		54.2	+29 21	7.3		+ .034 .011	13	R.A.
48	+69 .1228	Σ 2883*	22	8.4	+69 38	5.54	F	+ .078 .010	11	R.A.
49	+29 .4741	η Pegasi*		38.3	+29 42	3.10	G	- .004 .012	12	Long.
50	+19 .5094	Σ 3007*	23	17.8	+20 1	6.9		+ .061 .012	10	Long.

The comparison fields were chosen by method described in *Sproul Pub. No. 4* for those stars marked with asterisk.

MAGELLANIC PREMIUM

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1920

THE AMERICAN PHILOSOPHICAL SOCIETY

HELD AT PHILADELPHIA, FOR PROMOTING USEFUL KNOWLEDGE

ANNOUNCES THAT IN

DECEMBER, 1920

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MAGELLANIC GOLD MEDAL

TO THE AUTHOR OF THE BEST DISCOVERY, OR MOST USEFUL INVENTION, RE-LATING TO NAVIGATION, ASTRONOMY, OR NATURAL PHILOSOPHY (MERE NATURAL HISTORY ONLY EXCEPTED) UNDER THE FOLLOWING CONDITIONS :

1. The candidate shall, on or before November 1, 1920, deliver free of postage or other charges, his discovery, invention or improvement, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A., and shall distinguish his performance by some motto, device, or other signature. With his discovery, invention, or improvement, he shall also send a sealed letter containing the same motto, device, or other signature, and subscribed with the real name and place of residence of the author.

2. Persons of any nation, sect or denomination whatever, shall be admitted as candidates for this premium.

3. No discovery, invention or improvement shall be entitled to this premium which hath been already published, or for which the author hath been publicly rewarded elsewhere.

4. The candidate shall communicate his discovery, invention or improvement, either in the English, French, German, or Latin language.

5. A full account of the crowned subject shall be published by the Society, as soon as may be after the adjudication, either in a separate publication, or in the next succeeding volume of their Transactions, or in both.

6. The premium shall consist of an oval plate of solid standard gold of the value of ten guineas, suitably inscribed, with the seal of the Society annexed to the medal by a ribbon.

All correspondence in relation hereto should be addressed

To THE SECRETARIES OF THE

AMERICAN PHILOSOPHICAL SOCIETY

No. 104 SOUTH FIFTH STREET

PHILADELPHIA, U. S. A.

PROCEEDINGS

American Philosophical Society

CONTENTS

The American Philosophical Society

announces that an award will be made in the year 1921 of the

HENRY M. PHILLIPS PRIZE

The subject upon which essays are to be submitted is

**The Control of the Foreign Relations of the United States :
The Relative Rights, Duties, and Responsibilities of the President, of the Senate and the House, and of the Judiciary, in Theory and in Practice.**

The Essay shall contain not more than one hundred thousand words, exclusive of notes, and must be in the possession of the Society on or before December 31, 1920.

The Prize for the crowned essay will be Two Thousand Dollars, in gold coin of the United States, to be paid as soon as may be after the award.

Attention is called to the following regulations governing the award of the Prize:

Competitors for the prize shall affix to their essays some motto or name (not the proper name of the author, however) and when the essay is forwarded to the Society it shall be accompanied by a sealed envelope containing within the proper name and address of the author and on the outside thereof the motto or name adopted for the essay.

At a stated meeting of the Society in pursuance of the advertisement, all essays received up to that time shall be referred to a Committe of Judges, to consist of five persons, who shall be selected by the Society from nominations made by the Committee on the Henry M. Phillips Prize.

Essays may be written in any language, but, if not in English, must be accompanied by an English translation.

No essay which has been already published or printed, or for which the author has received any prize or profit of any nature whatsoever, shall be accepted in competition for the prize.

Essays must be typewritten on only one side of the paper, and six copies must be furnished by their respective authors for the use of the Committee of Judges.

The literary property of such essays shall be in their author, subject to the right of the Society to publish the crowned essay in its " Transactions " or " Proceedings."

The Society reserves the right not to award the prize if none of the competing essays is deemed worthy of it.

JOHN BASSETT MOORE,
DAVID JAYNE HILL,
SIMEON E. BALDWIN,
JOHN CADWALADER,
W. W. KEEN,
WILLIAM B. SCOTT,
President ex-officio,
Committee.

The essays must be sent, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A.

SUMMARY OF RESULTS. (SECOND LIST OF FIFTY STARS.)—*Concluded.*

No.	B.D. Number.	Star.	R.A., 1900. h.	R.A., 1900. m.	Declination, 1900.	Magnitude.	Spectrum.	Relative Parallax.	No. of Plates.	Coördinates.
27	+10°.2466	33 Virginis = Br 1706		41.3	+10° 6′	5.86	K	−0″.018 ± 0″.012	20	Long.
28	+17 .261	β 800	13	11.9	+17 33	7.0		+ .070 .010	12	R.A.
29	+35 .2462	OΣ 269*		28.3	+35 25	7.2		+ .067 .012	13	R.A.
30	+30 .2653	η Coronae Borealis*	15	19.1	+30 39	5.58	G	+ .085 .008	13	R.A.
31	+2 .3118	λ Ophiuchi*	16	25.9	+2 12	3.85	A	− .0037 .005	12	Long.
32	+32 .2896	72 w Herculis	17	16.9	+32 36	5.36	G	+ .064 .009	15	Long.
33	−0 .33	Σ 2173*		25.2	−0 59	5.34	G	+ .051 .009	13	Long.
34	+30 .3128	99 b Herculis*	18	3.2	+30 33	5.21	F_8	+ .043 .010	13	Long.
35	+38 .3466	Σ 2481 (π)*	19	7.7	+38 36	8.0		+ .016 .009	12	Long.
		Secchi 2 (π′)*				8.0		− .011 .009	12	Long.
36	+27 .3391	Σ 2525*		22.5	+27 7	7.5	G	+ .013 .013	12	Long.
37	+50 .2847	16 Cygni Pre. Comp.*		39.1	+50 18	6.26	F	+ .037 .012	14	Long.
	+50 .2848	16 Cygni Foll. Comp.*				6.37		+ .018 .006	14	Long.
38	+34 .3727	OΣ 387*			35 4	6.9	F_2	+ .015 .012	14	Long.
39	+6 .4357	β Aquilae = OΣ 532*		50.4	+6 9	3.90	K	+ .067 .011	13	Long.
40	+20 .4453	Σ 2637 = θ Sagittae A*	20	5.5	+20 37	7.0		+ .019 .004	9	Long.
	+20 .4453	Σ 2637 B*				8.3		+ .007 .009	12	Long.
	+20 .4452	Σ 2637 C*				7.8		+ .022 .011	12	Long.
41	+43 .3513	OΣ 400*		6.9	+43 39	7.5		+ .043 .007	11	Long.
42	+15 .4255	γ Delphini A	20	42.0	+15 46	4.49	G_5	+ .007 .010	14	R.A.
		γ Delphini B				5.47		− .008 .015	15	R.A.
43	+3 .4473	Σ 2737 = ε Equulei*		54.1	+3 55	5.29	F_5	+ .018 .012	12	Long.
44	+45 .3558	71g Cygni*	21	25.8	+46 6	5.35	K	+ .027 .008	11	R.A.
45	+45 .3562			26.1	+46 7.2	9.5		− .006 .009	10	R.A.
46	+45 .3566			26.8	+46 5.7	8.2		+ .002 .014	10	R.A.
47	+29 .455	Lalande 42883 − 5		54.2	+29 21	7.3		+ .034 .011	13	R.A.
48	+69 .1228	Σ 2883*	22	8.4	+69 38	5.54	F	+ .078 .010	11	R.A.
49	+29 .4741	η Pegasi*		38.3	+29 42	3.10	G	− .004 .012	12	Long.
50	+19 .5094	Σ 3007*	23	17.8	+20 1	6.9		+ .061 .012	10	Long.

The comparison fields were chosen by method described in *Sproul Pub. No. 4* for those stars marked with asterisk.

THE COMPONENTS AND COLLOIDAL BEHAVIOR OF PLANT PROTOPLASM.

By D. T. MacDOUGAL and H. A. SPOEHR.

Summary of Generalizations Previously Discussed.

The principal conclusions established by our previously described investigations which are of direct interest with relation to new results to be presented are as follows:

I. The protoplasmic mass of the active cell of the plant is a mixture of carbohydrates chiefly in the form of pentosans and albuminous substances, with a probable very low but undetermined proportion of lipins. In addition to the mucilaginous substances of the first, freely soluble sugars may be present in the cell solutions.

II. The principal components of plasmatic masses, the mucilages and the proteins, are mutually non-interdiffusible and hence when brought together in the cell by minute accretions or mixed in liquid form must be taken to form complex emulsions or mesh-works, and to occur separately both in disperse phase and disperse medium.

III. Of the components of such a mass the one which could be regarded as the more solid as having the lesser attraction for molecules of water, would tend to take position in the peripheral layer and to assume a greater density by lessening the liquid phase in the surface layer.

IV. The external layer of any colloidal mass or of any layer where two masses meet has invariably a composition determined by the constitution of the impinging masses. The formation of the cellulose wall which is first seen as a free plate between two separating protoplasts has a structure resulting from such action. The plasma of the plant being highly carbohydrate, the external layer is consequently largely anhydride of this material. The layers added internally to the initial wall must be of the same character. Furthermore for similar reasons, the external layer of the plasma, the semipermeable membrane, would also be high in carbohydrate. The en-

closing and boundary layers of nuclei and of all special bodies in the protoplasm would have a similar dual origin.

V. Highly proteinaceous plasmas would form external layers, which in conformity with the above, would not be cellulose or so high in carbohydrate. The chitinous skins of some animal organisms offer an inviting subject for examination in this connection.

VI. In so far as these limiting layers offer resistance to the passage of substances in solution equally in both directions, or as they allow the free passage of water and resistance to substances in solution, they form an osmotic machine by the action of which pressures may be set up internal to the cell and to plasmatic or nuclear masses. The implied phenomena designated as turgidity are most marked in plant cells where distentive forces of 40 or 50 atmospheres are found. It is to be noted also that when the two elements of a plasmatic colloid, the carbohydrate and the albumin, are unequally hydrated, as is the case in nearly all solutions, the superior increase of one element in the complex meshwork would set up something akin to osmotic pressure.

VII. Hydration increases or swelling is the result of the combination of molecules of water with colloidal aggregates of the mass. The addition of any substance which forms combinations with the colloidal carbohydrate or protein may give systems which attract, combine with and hold proportions of water different from those displayed when water only is present.

VIII. The hydration increase or swelling of an intermeshed pentosan-protein colloid, such as we imagine protoplasm to be, involves the possibility of the unequal increase of these two main components under the influence of any substance or ion, and the measurable alterations in volume will be the resultant of the effects of such a substance or ion upon the hydration of the unlike components.

IX. The pentosans are weak acids and in general their hydration capacity is lessened by hydrogen ions. Hydroxyl ions and compounds containing the amino-groups, such as may be in solutions of phenyl-alanin, alanin, asparagin and glycocoll, may exert an effect by which hydration capacity is increased above that in pure water. Mucilages derived from various sources show some differences in reactions to the solutions named while conforming to the generaliza-

tions given.   Their hydration is but little affected by the presence of the common sugars in the water of suspension or dispersion.

X. The albumins and their derivatives are amphoteric, being capable of dissociating both as acids or as bases.   Hydration in the presence of hydrogen ions may be much greater than in water and may reach the possible maximum, while that in the presence of hydroxyl ions and of various cations may also be in excess of that in water.   Gelatine as an example of this group shows such behavior but has a restricted hydration capacity in amino-acids such as gly-cocoll.   On the other hand, the swelling is proportional to the high hydrogen ion concentration of such amino-acids as aspartic acid, which is diabasic.

XI. Variations in the hydration total or volume may be ascribed to changes in the colloidal components of a plasma, to products of the resident metabolism, to the action of substances absorbed during hydration or to fluctuations in temperature.

XII. The changes in volume of a mass of colloidal material are usually not iso-diametrical during hydration.   Such alterations are determined by the structure of the jelly which may be so differ-entiated as to show expansion and contraction along one axis almost wholly.

XIII. The analysis of the implied facts has also demonstrated that growth is so essentially as to its nature, and so largely as to volume, a matter of hydration that the compounds which facilitate the swelling of phytocolloids and of cell-masses, facilitate or accel-erate growth.[1]

[1] MacDougal, D. T., " Hydration and Growth," Publ. 297 Carnegie Inst. of Wash., 1920, and " Hydration Effects of Amino-compounds," *Proc. Soc. for Exper. Biol. and Med.*, 17 : 35–36.   1919.

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CONCLUSIONS FOUNDED ON NEWLY OBTAINED RESULTS.

The further development of our knowledge on this subject has been attempted by experiments arranged to obtain evidence upon four topics, viz: (1) the proportions of carbohydrate and albuminous matter in a colloid of the highest hydration capacity; (2) the substances or ions of biological significance which would raise the hydration capacity of these phytocolloids to the highest limit; (3) measurement of the relative effects of some metallic bases upon a carbohydrate colloid; and (4) determination of the amplitude and continuance of alternating or repeated effects of renewed or replaced solutions.

1. By the use of the pentosan, agar, as representing the acid carbohydrate and of gelatine for the amphoteric albuminous component trials were made to ascertain what proportions of these substances would show hydration capacities of a range comparable to that of living matter. A mixture containing one part carbohydrate and three parts albuminous matter shows the highest general hydration capacity under the influence of hydrogen, hydroxyl ions and the ions which may be derived from amino-acids. Biocolloids high in albuminous matter swell most under the action of the hydrogen ion. Biocolloids containing 40 per cent. or more carbohydrates swell most in amino-compounds. Balanced biocolloids swell most in the presence of hydroxyl ions. These reactions are parallel to those of living and dried cell-masses of plants, and follow through the seasonal variations determined by chemical analyses.

2. Biocolloids of which more than a fourth is carbohydrate are highly sensitive to the action of hydrogen ions, which restrict hydration.

3. The basic histidine and glycocoll which is slightly on the acid side of neutral increase hydration in biocolloids containing more than 40 per cent. carbohydrate. Maximum swellings of 4300 per cent. by a mixture of 1 part agar and 3 parts gelatine in acid representing a high concentration for plant juices, and of 3930 per cent. by a mixture of 2 parts agar and 3 of gelatine in histidine are of great physiological interest. But little information concerning the presence or action of the basic amino-compounds in plants is available.

4. Glycocoll and glycocoll ester increase the swelling of agar. Glycocoll lessons swelling of gelatine, while glycocoll ester, glycocoll ester hydrochloride and glycocoll hydrochloride increase it beyond that shown in distilled water.

5. The hydroxides of the strong metallic bases limit the hydration of agar according to their position in the electromotive series. the least swelling taking place under the action of the strongest base at concentrations of 0.01 N with the apparent exception of rubidium. Beginning with the strongest the series runs K (Rb) Na Li.

6. The various effects of barium, calcium and strontium are not so clearly determined and the quantitative relations of these metals are not known definitely. Hydration values of agar at 0.01 N were $Sr(OH)_2 = 815$, $Ca(OH)_2 = 860$, $Ba(OH)_2 = 900$.

7. Hydration of agar in calcium hydroxide exceeds that in water at 0.0001 N of the hydroxide and this effect is also produced at 0.00001 N. Increase of hydration beyond that of water by dilute solutions of hydroxides of calcium, potassium, rubidium, potassium sodium and lithium is an effect we have hitherto ascribed to amino-compounds only. Excess values for aniline and ammonium hydroxide are given.

8. The incorporation of bases in agar lessens its hydration capacity in any concentration yet tested, and this is also true of biocolloids of which carbohydrates constitute more than half. In mixtures containing more gelatine hydration capacity in acids and in hydroxides may be increased by included bases. The inclusion of a metallic base and its presentation in a hydrating solution would give different results in a colloidal or plasmatic body such as a nucleus or chromosome.

9. The data in this article were secured chiefly by the swelling of trios of sections with a total volume of 4 to 8 cu. mm. under the auxograph in dishes into which 25 to 30 cc. of solution was placed and renewed at intervals of 12 and 24 hours. Such renewals were attended by accelerations in the rate and increases in the total swelling. Agar and biocolloids of agar and gelatine showed this action in a marked manner. Sections of equal parts of these two components exhibited reactions in which the exaggerated swelling resulting from renewals were partly retracted very slowly on the third

day. After this the exaggeration slowly decreased and the retrac-
tion increased until the two balanced about the eighth day. The two
movements continued for a total period of 67 days. It is suggested
that the exaggerated swelling following a renewal of the solutions
may be due to the formation of glycocoll agarate, the bulk of which
might be greater than that of the agar. Diffusion of this material
from the section would result in a retraction or shrinkage.

10. Plates of colloids cast on glass and prevented from shrink-
ing in area take on a heterotropic structure which varies in agar,
gelatine and in mixtures of the two. The swelling of an agar plate
is almost wholly in thickness so that the increase of a hydrated sec-
tion is denoted directly by the thickness reached. Gelatine plates
prepared in the same manner may increase as much as 60 per cent.
in length and width while swelling. Plates of mixtures of the two
swell from 6 to 16 per cent. in length and width, this amount being
modified by the character of the hydrating solution. These effects
which may play an important part in morphological procedure in the
cell, seem to indicate a meshwork structure of biocolloids as it does
not seem possible for emulsions to be differentiated in the manner
implied.

Hydration Tests of Various Biocolloids.

In the effort to ascertain the character of the biocolloids which
might show hydration reactions of the range and variety of proto-
plasm, empirical mixtures of agar and gelatine were made up and
cast into plates which were dried and then swelled under the auxo-
graph. Eight colloidal preparations were hydrated in water, hydro-
chloric acid, potassium hydroxide and glycocoll at 15° C. Trios of
sections were swelled under the auxograph in the usual manner, the
increases being calculated in percentages of original thickness by the
left hand number of each couple. Strips of the same material 50
to 80 mm. in length were placed in test tubes of similar solutions.
The resulting increases ranged from 2 to 12 per cent. in length and
width in the different colloids. These ratios were applied to the
increases in thickness to obtain the total volumes expressed in the
right-hand number of each pair in Table I.

TABLE I.

Hydration of Agar, Agar-albumin, Agar-gelatine and Gelatine in Terms of Thickness and Volume.

HCl, 0.01 N.		KOH, 0.01 N.		Glycocoll, 0.01 M.		Water.	
Th.	Vol.	Th.	Vol.	Th.	Vol.	Th.	Vol.
Agar 0.16 mm. at 15° C. Compiled Data.							
800	1,000	600	750	3,300	3,500	1,800	2,000
Gelatine 0.25 mm. at 15° C.							
1,960	4,700	1,640	3,190	600	850	960	1,570
Agar 1, Gelatine 3, 0.18 mm. 12–15° C.							
2,500	4,300	2,500	3,600	2,460	2,975	1,445	1,660
Agar 2, Gelatine 3, 0.19 mm 15° C.							
1,580	1,808	2,380	3,375	3,050	3,690	1,980	2,255
Agar 3, Gelatine 3, 0.25–28 mm. 14–16° C.							
1,300	1,573	2,720	3,802	2,200	2,565	1,860	2,250
Agar 3, Gelatine 2, 0.18 mm. 14–16° C.							
900	964	2,556	3,090	3,220	3,416	3,000	3,245

The data in the above table afford information on three main questions, viz., the probable constitution of living matter to be inferred from high hydration capacity, the nature of the colloids which show a sensitiveness in hydration to the action of the hydrogen ion, the hydroxyl ion and to ions which may be derived from amino-compounds, and lastly the differentiations in heterotropic swelling.

The highest swelling of the pentosan-protein mixtures is that of agar 1 gelatine 3 in hundredth normal acid. Such colloids may be present in the animal, but may be taken to be highly specialized or unusual in the plant and not shown by the cell-masses of the vegetative tracts. Chief interest centers in the colloids in which the carbohydrate and albuminous components each vary in forming 30 to 60 per cent. of the total and showing high hydration capacities in the hydroxides, in glycocoll and in water. These mixtures furnish an analogue of living matter of proved similarity of composition and action. Not only has it been possible to compound biocolloids which

would furnish conditions parallel to those in the plant, but the influence of changing proportions of the pentosans to the other cell-contents has been followed through the season by analyses in the chemical laboratory and by swelling tests of living and dried sections of the plants.[2]

Next to the composition and to the condition of the components, the matter of greatest importance is that of the ions or substances which may determine the course and amount of hydration. Acids, hydroxides and amino-compounds are to be included in a list of the substances of physiological importance. The action of hydrogen ions, of hydroxyl ions and of ions which may be derived from amino-compounds in the way of accelerating or retarding hydration may be shown by expressing the swelling values produced in terms of those obtained in water taken as 100 given in Table II.

TABLE II.

Hydration of Colloids in Hydrochloric Acid, Potassium Hydroxid and Glycocoll at 0.01 N with that in Water as 100.

Hydrochloric Acid.		Potassium Hydroxide.		Glycocoll.	
Th.	Vol.	Th.	Vol.	Th.	Vol.
Agar.					
44	50	33	42	183	185
Gelatine.					
204	300	171	200	63	54
Agar 1 Gelatine 3.					
173	270	173	225	170	186
Agar 2 Gelatine 3.					
80	67	120	150	154	163
Agar 3 Gelatine 3.					
70	70	146	170	112	114
Agar 3 Gelatine 2.					
30	30	85	95	107	106

[2] MacDougal, D. T., "Hydration and Growth," Publ. 297 Carnegie Inst. of Wash., 1920, p. 132.

The effect of the hydrogen ions which are present in a concentration of pH $= 3$ in the acid solution is to induce a high swelling in gelatine and to produce a lessened swelling as this component is lessened and as the carbohydrate is increased. A finely parallel series was obtained in tests of living sections of Opuntia from last December to March in which the proportionate swelling in acid varied from 80 per cent. in December to 77 in January, 7 in February, rising to 78 in March and falling to 64 in April, as compared with water at 100. The course of the pentosans was not followed at the same time, but in a previous year the variation in the pentosan content of similar material was from 10 in late December to 4.7 in mid-January, 6 in mid-February, and to 5.5 late in March, which allowing for seasonal differences, gives a fair parallel.

The hydroxide is seen to cause a swelling of both agar and of gelatine less than in water, and to cause a swelling of gelatine something less than in acid. Its general effect is to lessen hydration as the carbohydrate component of the biocolloid becomes greater, although an aberrant high swelling is shown by mixtures of equal parts of gelatine and agar.

Turning now to the plant material which shows the seasonal variation of pentosans noted above the swelling of living material varies from comparative values of 100 in December, 103 in January, 100 in February, and 110 in March, facts in no wise discordant with the seasonal changes and probable accumulation of metallic salts in the cells.

Glycocoll produces a maximum effect on agar and a minimum on gelatine or the albuminous component of biocolloids. Its maximum accelerating effect seems to be upon mixtures containing 25 to 40 per cent. of the carbohydrate, although in all cases it causes agar mixtures to hydrate to a point beyond that which might be reached in water.

If we now seek to ascertain what type of biocolloid is capable of the greatest average hydration or growth under the influence of these substances and of the basic histidine, it will be found in a mixture which is composed of 1 part carbohydrate and 3 parts albuminous material. Biocolloids containing more carbohydrate than albuminous matter would be most sensitive to the presence of hy-

drogen ions, and their growth would be markedly limited by acidity. Such mixtures would also be modified something less by hydroxy! ions. All types of biocolloid would respond by increased hydration to the presence of amino acids as shown by the relative swellings in glycocoll and in histidine.

The results with the basic histidine and of its salt histidine dihydrochloride, which reacts as an acid, are as given in Table III.

TABLE III.

Swellings of Agar, Gelatine and Mixtures in Percentages of Original Thickness and Volume.

Histidine, 0.01 *M.*		Histidine Dihydrochloride, 0.01 *M.*		Water.	
Th.	Vol.	Th.	Vol.	Th.	Vol.
Agar 0.15 mm. at 15° C.					
2,500	....	900	....	3,100	....
Gelatine 0.28 mm. at 14–16° C.					
1,723	3,103	1,600	4,200	1,400	3,150
Agar 2 Gelatine 3, 0.19 mm. at 15° C.					
3,470	3,930	1,445	1,780	1,980	2,225
Agar 3 Gelatine 3, 0.25 mm. at 15° C.					
....	....	1,200	1,320	1,860	2,250
Agar 3 Gelatine 2, 0.25 mm. at 14–16° C.					
3,472	3,755	800	842	3,000	3,245

Mixtures consisting of 40 to 60 per cent. of the two main components are seen to give the highest swelling values in histidine yet obtained by biocolloids by treatment with any reagent. Furthermore this amino-compound acts to increase the swelling of gelatine and all mixtures containing it to a point beyond that which is possible in water. Its acid salt has the well-known effect on agar, gelatine and their mixtures. These features are illustrated by Table IV. in which the values are given in terms of water as 100.

In addition to the high hydration caused in the above mixtures by histidine, attention has been previously called to a similar action

by glycocoll on agar. No final explanation for this behavior has as yet been obtained. Of great interest, however, are the results obtained with a number of glycocoll compounds. Swelling tests were made in the usual manner with the following compounds: (1) Glycocoll which is approximately neutral in reaction and amphoteric in behavior. (2) Glycocoll ethyl ester; in this compound the acid radicle has been neutralized, is distinctly alkaline and acts as a weak

TABLE IV.

Histidine.		Histidine Dihydrochloride.	
Th.	Vol.	Th.	Vol.
Agar.			
80	....	30	....
Gelatine.			
124	100	114	130
Agar 2 Gelatine 3.			
176	176	73	80
Agar 3 Gelatine 3.			
....	....	65	60
Agar 3 Gelatine 2.			
116	116	27	27

base on the swelling of agar. However, in solutions of this substance agar does not attain the same swelling above that of water as it does in the amphoteric glycocoll. On account of the relatively rapid hydrolysis of glycocoll ester in water, fresh solutions were frequently prepared for renewal in the swelling tests. (3) Glycocoll ethyl ester hydrochloride in which both the basic and acid portions of the glycocoll molecule have been neutralized. (4) Glycocoll hydrochloride which reacts as an acid in water solution and shows the typical acid behavior in the swelling agar. The solutions were all in 0.01 molar concentration. The absolute increases in terms of thickness and volume are as below:

TABLE V.

Water.	Glycocoll 0.01 M.	Glycocoll Ester 0.01 M.	Glycocoll Ester Hydrochloride 0.01 M.	Glycocoll Hydrochloride 0.01 M.

Agar.
Sections 0.15 mm. Thick at 15° C.

3,220	4,130	3,360	1,530	1,000

(Increases in width and length very slight.)

Gelatine.
Sections 0.23 mm. Thick at 15° C.

Th.	Vol.	Th.	Vol.	Th.	Vol.	Th.	Vol.	Th.	Vol.
960	1,570	600	850	1,170	2,240	910	1,180	1,280	2,880

The above data reduced to terms of swelling in water as 100 give values as in Table VI.

TABLE VI.

SWELLING OF DRIED PLATES OF AGAR AND GELATINE.

Water.	Glycocoll.	Glycocoll Ester.	Glycocoll Ester Hydrochloride.	Glycocoll Hydrochloride.

Agar.

100	128.30	104.35	47.50	31.07

Gelatine.

Th.	Vol.	Th.	Vol.	Th.	Vol.	Th.	Vol.	Th.	Vol.
100	100	62	54	122	143	95	75	134	180

Glycocoll and its ester are seen to increase the swelling of agar and to lessen that of gelatine. The two salts exert the classical effects of retarding the swelling of agar. The swelling of gelatine in the glycocoll estes hydrochloride is slightly less than in water, while the swelling of gelatine in the glycocoll ester hydrochloride is higher as in an acid solution.

HYDRATION OF AGAR IN SOLUTIONS OF VARIOUS HYDROXIDES.

The delicacy of reaction prevailing in the behavior of agar towards hydrogen and hydroxyl ions as well as various cations is

exemplified in the swellings in solutions of various bases and deriva-
tives of glycocoll.   It became apparent in the earlier stages of our
work that the effects of the alkaline hydroxides were by no means
equivalent, and a series of preparations were run for the purpose of
securing comparisons of the action of potassium, rubidium, sodium,
lithium, barium, strontium and calcium.   The values obtained are
given in Table VII.

TABLE VII.

Swelling of Agar in Strong Alkaline Hydroxides.
Sections 0.14 mm. Thick at 17° C.

	0.01 N.	0.001 N.
KOH	1,535	3,430
RbOH	1,635	3,500
NaOH	1,645	3,430
LiOH	1,820	3,430
Water	3,000 to 3,070	

When these absolute values are compared with that obtained in
water the data in Table VIII. are obtained.

TABLE VIII.

Swelling of Dried Agar Plates 0.14 mm. in Thickness at 17° C. in Solu-
tions of Alkaline Hydroxides which were Renewed Every 12 Hours.
Total swelling of dried agar plates in water 3,035 per cent.

Normal Concen- tration.	Water.	KOH.	RbOH.	NaOH.	LiOH.
0.01	100	50.3	53.8	54.8	60.0
0.001	100	113.0	115.3	113.0	113.0

It is to be seen that these alkaline hydroxides may be carried to
an attenuation where they may cause a swelling of agar greater than
in water, an effect hitherto found only with amino-compounds.   The
stronger the base as indicated by its position in the electromotive
series, the more does it restrict hydration.   All reverse that effect
and become accelerating agents at a greater dilution.   Rubidium is
the exception in the table, and its aberrant position may be ascribed
to error until material is available for a repetition of the tests.

In the hydroxides of the alkaline earths the variations are not
so clearly defined.   Unfortunately the quantitative relations of these

metals are not definitely known, and further complications may arise in the different solubility and behavior of the carbonates which naturally are always formed in spite of frequent renewals of the solutions. The series of tests which were made to secure information on this matter yielded the following results:

TABLE IX.

SWELLING OF AGAR IN ALKALINE HYDROXIDES IN PERCENTAGES OF ORIGINAL THICKNESS.

	0.01 N.	0.001 N.	0.0001 N.	0.00001 N.
	Sections 0.14 mm. Thick at 15° C.			
Ba(OH)$_2$	900	1,145	2,430	2,400
	Sections 0.14 mm. Thick at 15° C.			
Ca(OH)$_2$	860	1,220	3,200	3,200
	Sections 0.16 mm. Thick at 15° C.			
Sr(OH)$_2$	815	1,565	2,565	2,665

The conversion of the data in Table IX. to terms of swelling in water results in the following data:

TABLE X.

SWELLING OF DRIED AGAR PLATES AT 15° C. IN SOLUTIONS OF ALKALINE EARTH HYDROXIDES WHICH WERE RENEWED EVERY 12 HOURS.

Thickness of dried plates in Ba(OH)$_2$ and Ca(OH)$_2$ series 0.14 mm., in Sr(OH)$_2$ series 0.16 mm. Total swelling in water 3,035 per cent.

Normal Concentration.	Water.	Ba(OH)$_2$.	Sr(OH)$_2$.	Ca(OH)$_2$.
0.01	100	29.6	26.8	28.3
0.001	100	47.7	51.6	40.2
0.0001	100	80.3	84.8	106.0
0.00001	100	79.4	88.0	106.0

It is seen that even at the greater attenuations, barium and strontium hydroxides limited hydration. As it appeared important to test the favorable effect of calcium solutions of various concentrations, a detailed series of tests was carried out. The actual increases in percentages of original thickness are given in the upper line of the table below and the values as compared with water as 100 in the line below.

TABLE XI.

SWELLING OF DRIED AGAR PLATES AT 15° C. IN SOLUTIONS OF Ca(OH)$_2$
WHICH WERE RENEWED EVERY 12 HOURS.

Normal Concentration.	Water.	0.02.	0.01.	0.002.	0.001.	0.0002.	0.0001.	0.00001.
	3,000 3,070	565	860	1,000	1,220	2,500	3,200	3,200
	100	18.6	28.5	33.0	40.2	82.4	105.4	105.4

The augmenting effect of calcium hydroxide which was found in concentrations of 0.0001 is here seen not to be exhibited in a solution containing twice this amount, and is not increased when a reduction below this concentration is made.

The effects of ammonium hydroxide and aniline on the swelling of agar are of direct interest in any discussion of the relative action of the weaker and stronger bases.

Data for comparisons have been conveniently grouped in Table XII.

TABLE XII.

SWELLING OF DRIED AGAR PLATES AT 15° C. IN SOLUTIONS OF VARIOUS HY-
DROXIDES, RENEWED EVERY 12 HOURS, IN TERMS OF WATER AS 100.
Total swelling of dried agar plates in water 3,950 per cent.

Normal Concentration.	Water.	Aniline.	Ammonium Hydroxide.	Ethyl-amine.	Lithium Hydroxide.	Sodium Hydroxide.	Potassium Hydroxide.
0.01	100	110	25	31	24	21	21
0.001	100	100	115	88	40	35	29

The behavior of agar in the weak bases ammonium hydroxide, ethylamine and aniline on the one hand and in lithium hydroxide, sodium hydroxide and potassium hydroxide on the other, exhibits some interesting differences, particularly in the more dilute solutions.[3]   Owing to the fact that in solutions of ammonium hydroxide and ethylamine there exist equilibria respectively between dissolved NH$_3$ and the hydroxide, and between dissolved C$_2$H$_5$NH$_2$ and its hydroxide, the condition in solutions of these substances particularly in the more concentrated solutions offer a rather complicated situa-

[3] MacDougal, D. T., and Spoehr, H. A., " The Swelling of Agar in Solutions of Amino Acids and Some Related Compounds," *Bot. Gaz.*, 69: 1920 (in press).

tion not very dissimilar from that obtaining in solutions of the amino acids.   It will be recalled that aniline is a weaker base than ammonium hydroxide while ethylamine and the hydroxides of lithium, sodium and potassium are stronger.

EFFECT OF INCLUDED BASES ON SWELLING OF BIOCOLLOIDS.

The hydration of plates or sections of dried colloids in solutions involves questions of penetration and of the formation of compounds in the external parts of the section which may modify the hydration of the interior of the mass.   The conclusion was reached in work set forth in previous papers that acids, metallic salts and

TABLE XIII.

SWELLINGS OF DRIED SECTIONS OF BICOLLOIDS WITH INCLUDED BASES IN PERCENTAGES OF ORIGINAL THICKNESS.

HCl 0.01 N.	KOH 0.01 N.	Histidine Dihydrochloride 0.01 N.	Glycocoll 0.01 N.	Water.
	Agar 2, Gelatine 3, KOH 0.000,05 N			
	NaOH 0.000,025 N			
	Ca(OH)$_2$ 0.000,025 N			
	Sections 0.1 mm. Thick at 16–17° C.			
2,100–3,220	2,950–3,570	1,700–2,050	2,750–3,030	2,050–2,380
	Agar 3, Gelatine 3, KOH 0.001 N			
	NaOH 0.0001 N			
	Ca(OH)$_2$ 0.0001 N			
	Histidine 0.001,4			
	Section 0.09 mm. Thick at 16–17° C.			
850–875	2,220–2,680	1,700–1,800		2,050–2,260
	Agar 3, Gelatine 2, KOH 0.000,05 N			
	NaOH 0.000,025 N			
	Ca(OH)$_2$ 0.000,025 N			
	Sections 0.14–0.15 mm. Thick at 15° C.			
500–521	2,330–2,820	1,570–1,730	2,850–3,200	2,300–2,780

amino-compounds incorporated in colloids exerted a greater effect, generally a lessening action on swelling than the same amount of the reagent applied in aqueous solution.

Furthermore it may be said in particular that in no case did an

inclusion in the carbohydrate, agar, increase its hydration in water, and this holds true for such substances as asparagin, glycocoll, etc., which cause a hydration much in excess of that taking place in water when applied in aqueous solution.

As a further contribution to this matter the hydroxides of calcium, sodium and potassium were incorporated in biocolloids in proportions in which no lessening effect would be exerted by solutions which would bring the same amount of the bases into action on the colloids. The results of this series of tests are given in Table XIII.

The hydration values of the mixtures of agar 2 parts and gelatine 3 parts in water are not materially different from those of some colloidal mixture free from the bases. The presence of the bases increases hydration in acid and in potassium hydroxide, but lessens it in glycocoll, as may be seen by comparison with Table I. When the proportion of agar is increased and that of gelatine decreased as in a mixture of 3 parts agar and 2 of gelatine, the swelling in water is lessened notably, and decreases occur in all solutions, a fact which may be ascribed directly to the action of the carbohydrate component. The bases included in these biocolloids were present in proportions one fourth of that in which excess swelling was caused in solutions of calcium and sodium, and one five hundredth in the case of potassium, although the total amount of bases would be little short of that present in any one of the solutions.

It is suggested that the reversal of the effect of included bases on the swelling of biocolloids must be at a greater attenuation than when in solution. Such restricting effect rises with the proportion of carbohydrate present.

It is evident that the inclusion of a substance or ion in a colloidal structure results in hydration relations of a different character from those which appear when the substance in question is presented in the hydrating solution. In the latter case it seems theoretically possible that differentiations of external layers of the hydrating masses may take place which might result in swellings due in the last analysis to something like osmosis.[4]

[4] MacDougal, D. T., "Hydration and Growth," Publ. No. 297 Carnegie Inst. of Wash., 1920, see pp. 32, 33, 44, 46, 47, 48, 50, 58, 59, 70, 72, 75.

The presence of any substance in the nucleus, chromosomes or plasmatic bodies would give colloidal reactions materially different from those to be expected when such substances are presented in the cell sap or fluids according to the facts presented above.

Maximum Effects Produced by Renewing Solutions.

Closely related to the effects resulting by replacement of one solution by another are those produced by renewing solutions. The methods of auxographic measurement which have been used so extensively in these experiments entail the immersion of a trio of dried sections of a total volume of about 4 to 8 cu. mm. in 25 to 30 cc. of solution, the most common concentration of which was 0.01 N. The procedure of drawing off this solution and replacing it with a fresh solution at intervals of 12 or 24 hours has been followed since 1918.

It has been noted that at the first renewal made after the experiment has been started an acceleration of the swelling would ensue This speeding up has been attributed to two causes. First, as much as 10 per cent. of the colloid may be drawn out into solution and the presence of such a solution around the mass would operate to lessen the rate of absorption of water by the more solid sections. Secondly, the ions of the substances in the hydrating solution pass into the colloidal mass and enter into combination with the aggregates, thereby lessening the concentration of the solution and consequently its accelerating effect on hydration. The renewal of the solution would remove the colloidal suspension about the sections and would furnish a solution capable of exerting a hydrating effect equivalent to the original, which would speed up the absorption of water.[5]

Usually these effects are shown during the first two or three changes in swellings in which the total effect is practically finished in ten days at 15° C.

Dried sections of agar and a number of mixtures of agar and gelatine are seen to show a much more pronounced and long continued reaction of this kind. The characteristic effect has been produced so far only by attenuated solutions of hydroxides of weak metallic bases, by glycocoll and the basic glycocoll ester.

[5] MacDougal, D. T., and Spoehr, H. A., *Bot. Gaz.*, 69: (in press). 1920.

Some mention of this action of glycocoll has already been made in a previous article, but the effects shown by agar-gelatine mixtures in which the two principal components vary between 40 and 60 per cent. were so marked that attention was again directed to their measurement and to the formulation of some explanation.

The most pronounced effects were secured by hydrating sections of equal parts gelatine and agar, 0.25 mm. in thickness at 14–16° C., which approximated a condition of saturation in ten days with an increase of 2,640 per cent. in thickness and of 2,720 per cent. in volume, the material being highly heterotropic.

The first renewal of the solution caused a sudden enlargement which in 3 hours added 140 per cent. to the thickness of the sections. The accelerated enlargement following the second change was about 120 per cent., the sections coming to rest on the first day in 4 hours and in 3 hours on the second change. The accelerated swelling on the third day amounted to 100 per cent., coming to rest in something over 2 hours, after which a slow shrinkage occurred by which a third of the previously gained amount was lost. The fourth acceleration amounted to 120 per cent. with a subsequent loss of one third this amount in the next twenty-four hours. The fifth reaction gave a swelling of 100 per cent. followed by a loss of half this amount. The sixth reaction gave an increase of 100 per cent. followed by a loss of equal amount. The seventh reaction gave an increase of 90 per cent., followed by a loss of 50 per cent. The eighth showed a gain of 80 per cent. and a loss of equal amount; the ninth a gain of 70 per cent. and a loss of equal amount; the tenth a gain of 60 per cent. and a loss of 60 per cent.; the eleventh a gain of 80 per cent. and a loss of 60 per cent. The twelfth change gave a gain of 60 per cent. and a loss of 50 per cent.; the thirteenth a balanced loss and gain of 60 per cent., after which the change in both directions became equivalent so that on the sixtieth day the alteration amounted to 40 per cent. of the original thickness, which decreased to 20 per cent. a week later when the observation was closed, 67 days from the beginning. The whole series of reactions in range and intensity might be said to offer a fair parallel to the life of some short-cycle seed-plants, in which any substance or combination of substances which might furnish the basis for the recurrent action might be re-

newed by metabolism instead of being furnished as in the experiments described.

Of the various suggestions which might be offered in explanation of the reaction, the most plausible one seems to be one in which it is assumed that the replacement of the glycocoll solution would result in the formation of a theoretically possible glycocoll agarate, the bulk of which might be greater than the total of its separate components, and hence the combination would result in an immediate further swelling. The slow diffusion of this substance out of the sections would lessen or prevent the absorption or penetration of the glycocoll solution from the outside so a shrinkage would result. In the case of the hydroxides and mixtures containing gelatine the combination most probably would be that in which a potassium gelatinate would be formed and its slow diffusion would be accompanied by a shrinkage. In any case the changes in volume seem to have escaped observation hitherto and to be of such range as to have significance for the mechanism of the cell.

STRUCTURE AND HETEROTROPIC SWELLING OF·COLLOIDAL MIXTURES.

That dried sections of colloids do not show equivalent expansion in all directions due to the development of structure in disiccation has long been known and has been variously discussed in previous articles. Extreme differentiation is shown by agar, plates of which may be so dried that they increase but 2–4 per cent. in length and width while swelling 3,000–4,000 per cent. in thickness. Gelatine on the other hand may be cast in such form that it increases 10 to 60 per cent. in length and width while hydrating 1,000 to 3,000 per cent. in thickness. Mixtures of agar and gelatine do not show more than 10–16 per cent. increase in superficial measurements. No accurate measurements have been made, but the data in Tables I. and II. suggest that the swelling in the axes in which the colloid did not shrink when desiccating may be modied in a distinct manner characteristic of the substances acting upon the colloid. Thus the relative increase in volume is greater in a mixture of 1 part agar and 3 of gelatine in hydroxide than it is in acid, and other differentiations may be found by inspection of these tables.

The superposed effects of alternated solutions may also be taken to rest partly upon the complex structure of pentosan-protein compounds. The replacement of one swelling reagent by another of higher effect on agar does not have the effect of inducing a total hydration of agar in excess of that which might be induced by the second solution applied at the beginning. On the other hand the replacement of a solution which might produce a maximum hydration by another which has a lesser effect does not usually result in reducing the water content of the colloidal mass to the amount which it would have taken up if swelled in this reagent from the beginning.

The mixture of agar and gelatine however results in a condition or structure in the colloidal mass in which it is possible to produce or secure superposed effects. So far the only available example of this action was a case in which an agar-gel mixture was first hydrated to full capacity in histidine dihydrochloride, making an increase of 920 per cent.; the amino salt was now replaced with potassium hydroxide, making a total swelling of 2,950–3,447 per cent. as compared with 2,556–3,090 per cent. which takes place in the hydroxide alone.

If the mass be supposed to be made up of alternating strands or globules of the carbohydrate and albuminous elements, it is clear that the action of the salt to which the sections were first exposed would result in a much greater hydration of the gelatine than of the agar. Replacement with the hydroxide would not result in the reduction of the salt induced swelling but would increase it at the same time facilitating hydration of the agar.

6 MacDougal, D. T., " Hydration and Growth," Publ. No. 297 Carnegie Inst. of Wash., 1920, see pp. 17–20.

THE PHOSPHORESCENCE OF RENILLA.

By G. H. PARKER.

(Read April 24, 1920.)

The phosphorescence of the sea-pansy *Renilla* has been known for a long time. As early as 1850 Louis Agassiz observed that *Renilla reniformis,* the common species of our southern waters, "shines at night with a golden green light of a most wonderful softness." This is also true of *Renilla amethystina* of southern California. If a fresh specimen of this species that has been exposed to daylight is carried into a dark-room and stimulated by being gently prodded, no phosphorescence is observable, but if the same experiment is tried at night, the colony glows with a wonderfully clear blue-green light.

If during daylight non-phosphorescent Renillas are transferred to a dark-room and kept there, they begin to show phosphorescence on stimulation in about half an hour and attain what seems to be their maximum under these circumstances in about an hour. The phosphorescence thus developed seems never to reach the degree of brightness seen during the night. This probably depends upon a natural daily rhythm in the animal's metabolism. Phosphorescence induced during the daytime by placing a colony for an hour or so in the dark is completely lost on exposure to daylight for about five minutes. If during the night a colony that showed a naturally acquired bright phosphorescence is illuminated by strong light, the ability to produce light steadily decreases, but is never entirely lost, showing that either artificial light is not so effective in this respect as daylight or that during the night *Renilla* is more efficient in producing the substances necessary for the production of light than during the day.

Renilla is phosphorescent only on stimulation. If in the night a spot on its upper surface is stimulated mechanically or electrically, luminous ripples emanated from this spot and spread out concen-

trically over its surface like waves on the smooth face of a pond into which a pebble has been thrown. If a fine needle point is used as a stimulus, a single point of light can be excited and this point will glow some seconds but without becoming a center from which luminous waves spread.

When a glowing *Renilla* is examined under a hand lens, the parts from which the light emanates are seen to be small masses of light-colored material that stud the upper surface of the animal and that surround the bases of the zooids. Apparently light emanates from no other source. No phosphorescence has ever been excited from the peduncle by which the animal anchors itself in the sand, nor from the under surface of the disc. The phosphorescence is strictly limited to the upper surface and apparently to the light-colored material of that surface. If a bit of this material is cut from the disc at night-time and carried into a dark room and crushed between glass, a momentary sparkling can be seen. If this experiment is tried with a bit of the purple flesh of the upper surface, no such sparkling is produced. Hence it is clear that the source, of the phosphorescence is the light-colored material of the upper surface of the disc.

This light-colored material on close inspection is seen to be composed of two substances: a whitish chalky substance and a light-yellowish crystalline one. These two substances are so intimately associated that it is impossible to separate them satisfactorily or in most places to determine by direct inspection which is responsible for the light. Only on the edge of the disc is it possible to make decisive observations. Here the two substances form a well-marked double fringe, the outer one being composed exclusively of the white material, the inner one of the yellowish. When phosphorescence is excited on the adge of the disc, it can be seen that the light is resident in the white fringe and not in the yellow and hence the former material must be regarded as the true source of the phosphorescence. When this material in a luminous state is inspected under a hand lens it is indescribably beautiful; the light it gives out is of an intense blue-green color with all the play that one sees in a brightly illuminated opal.

The mechanical or electrical stimulation of *Renilla* at night re-

sults in what seems to be a series of luminous waves that emanate concentrically from the region of stimulation. When one of these wave fronts is closely scrutinized, it is found to be not a continuous line but a series of luminous points which represent the small masses of white material already alluded to and which for the moment lie in what would be a continuous wave front. Thus the appearance of a luminous wave is due to the momentary glowing of one concentric line of points after another as the impulse that induces the phosphorescence spreads from the center of stimulation outward.

When the disc of *Renilla* is cut into and the animal is subsequently excited to phosphoresce, the luminous waves pass round the incisions without interruption so long as organic continuity is present. If the disc is cut nearly in two transversely, the waves of phosphorescence can be started in either piece and will pass thence over the connecting bridge to the other place. If the disc is cut into a scroll that can be unfolded into an elongated form, stimulation at one end will start a luminous wave that will pass to the other.

If a *Renilla* is split longitudinally through its chief axis, the two halves remaining attached only through the distal part of the peduncle, the stimulation of one half calls forth a flash of light in that half which, after it has subsided, is followed by another flash in the other half. The second flash follows the first at such an appreciable interval of time that the preparation seems to wink first with one eye and then with the other. Here the interval between flashes is due to the transmission of the wave of excitation through the nonluminous peduncle, for if the peduncle is completely split no such transmission occurs even if the two halves are closely applied to each other. This observation shows that the luminous waves are under the control of some form of transmission, non-luminous in character, that spreads in wave-like fashion and for which the phosphorescent waves may be said to be luminous replicas. It also makes clear that the peduncle can transmit the impulses that excite luminosity in other parts. Not only can be peduncle transmit these impulses, but it can also originate them, for if the tip of the peduncle of *Renilla* is pinched, after a moment the disc flashes in waves of phosphorescence.

As might be inferred, any portion of the disc carrying the white

material already alluded to can on stimulation be made to glow. Thus right or left halves, quadrants, centers, margins or even minute fragment will on appropriate treatment give out light.

The impulses that induce phosphorescence are profoundly influenced by such anesthetics as magnesium sulphate. If a preparation is made by cutting a disc of *Renilla* almost in two by a transverse incision and, after determining that the connecting bridge will transmit luminous waves, this bridge is covered with crystals of magnesium sulphate, the waves of light in ten minutes or so will be blocked at the bridge and light will be produced in only that part of the disc which is directly stimulated. After half an hour or so in pure seawater the bridge will again transmit the luminous waves.

If a V-shaped preparation is made from a *Renilla* by splitting it through its long axis except at the distal end of the peduncle, it will be found, as already stated, to transmit impulses for light production from one half to the other through the partly split peduncle. If the unsplit portion of the peduncle is now covered with crystals of magnesium sulphate, in five to ten minutes no impulses to illumination will pass through it, for when one half is excited to glow the other does not follow by producing a flash. Recovery from this condition occurs after the preparation has been for half an hour or so in pure seawater.

The rate at which the luminous waves traverse the disc of *Renilla* is a relatively slow one. To determine it, strips of tissues were cut from the edge of the disc and pinned out in seawater. They measured five to eight millimeters in width and about ten centimeters in length. After night had come on these strips could be stimulated by touching one end gently with a metal rod whereupon a single wave of light would pass rapidly over the length of the strip. This could be timed by a stop-watch. Five such preparations were tested with the result that the average rate of transmission was found to be 7.39 centimeters per second. This rate agrees almost exactly with that for the withdrawal of the zooids in Renilla, namely 7.83 centimeters per second and indicates that both these processes are controlled by a single mechanism. As these rates are close to that of the nerve-net of the sea-anemone *Metridium,* namely, 12 to 14 centimeters per second, the common mechanism upon which

they depend is probably nervous. Certainly these rates are in strong contrast with the rates of transmission of certain peristaltic movements that are known to pass over the peduncle and the disc of *Renilla*. These travel 0.15 centimeters to 0.12 centimeters per second, one fiftieth to one sixtieth as fast as the other waves do, and are very probably muscular in origin. Hence, the conclusions that the withdrawal of zooids and the phosphorescence of *Renilla* are controlled by a single form of transmission and that this transmission is neurogenic rather than myogenic in origin.

If the transmission by which the phosphorescent waves of *Renilla* are produced is nervous in character, it ought to vary with the temperature and such seems to be the case. Thus in one set of trials the rate per second was found to be at 11° C. 4.0 centimeters, at 21° C. 7.7 centimeters and at 31° C. 20.7 centimeters. In another set it was at 15° C. 6.5 centimeters per second, at 20° C. 8.3 centimeters and at 25° C. 12.2 centimeters. As is shown in the second set, an increase of 10 degrees in temperature is accompanied by an approximate doubling of the rate, 6.5 to 12.2 centimeters per second. Much the same is true of the first set except for its highest member. If in this set the rate per second at 21° is taken to be 7.7 centimeters, at 11° it ought to be half that or 3.85 centimeters which is very close to the oserved rate of 4.0 centimeters per second. On the same basis at 31° a rate of twice 7.7 centimeters or 15.4 centimeters per second should be looked for but the rate actually observed was somewhat higher than this, namely 20.7 centimeters per second. Notwithstanding this divergence, which is associated with a rather extreme temperature, it may be stated that over the greater part of the temperature range for every interval of 10 degrees the higher rate is approximately twice the lower one. Although the usual interpretation of this condition has been more or less questioned recently, it is generally assumed, in accordance with the van't Hoff law, that such relations in rates are indicative of chemical rather than of physical processes, an assumption that would aline the kind of transmission that occurs in the phosphorescent wave of *Renilla* with the burning of a trail of gunpowder rather than with some form of transmission of a purely physical type.

THE EINSTEIN THEORY.

By E. P. ADAMS.

When your Programme Committee, through the President, asked me to read a paper on the subject of Relativity and the Gravitation Theory at the General Meeting of the Society, I assumed that it was in the thought that one who had occupied himself mainly with the study of concrete physical phenomena might be able to contribute something towards a definite physical conception of the new theory.

I shall not take more time to go into the question as to how the theory of relativity was developed than merely to say that a number of physical phenomena are known which appear to be in contradiction to the system of mechanics founded on Newton's laws of motion. Now Newton's laws are based upon the fundamental concepts of space, time and matter. The space of Newton is the space of Euclid—the space of our ordinary experience. The time of Newton is the time that we ordinarily think of—a conception wholly independent of our space conception. And matter for Newton is the matter that is perceived by our senses.

Equally fundamental in Newton's mechanics to the three concepts of space, time and matter is that of force—the cause of every change in motion. That the idea of force is as fundamental a notion to us as that of matter there is little doubt; they are both revealed to us by our senses; our muscular sense gives us very directly a realization of force. When, however, a system of mechanics is built up with force as one of the four fundamental concepts a certain indeterminateness arises. I need mention only the controversy that still goes on as to the exact interpretation of centrifugal force, and other forces that we have to consider that are certainly not the cause but the result of motion. And when we extend our system of mechanics so as to cover all physical phenomena forces of other kinds must be postulated—electric, magnetic,

molecular, chemical forces—forces of which we have no direct sense, but which nevertheless must be regarded as having a real existence.

In an attempt to clear away the indeterminateness involved in the conception of force as fundamental, and the complexity inherent in a multiplicity of forces, Hertz developed a system of mechanics in which the idea of force as one of the fundamental concepts was banished. In this system of mechanics all forces are the result of constraints arising from concealed or cyclic motions. If we should experiment with a rapidly spinning wheel enclosed in a box, not knowing what there was in the box, we should come to the conclusion that the box was in a field of force quite different from a simple gravitational field; or in other words the potential energy of the box would appear to be different from its potential energy with the wheel at rest. But knowing of the wheel in rotation, what would appear as potential energy arising from an external field would really be kinetic energy of cyclic motion. So Hertz attempted to interpret every force acting on a system as arising from cyclic motions, with a single law governing the motion of the system—the law of the straightest path. There is a close relation between Hertz's system of mechanics and Einstein's theory of gravitation to which we shall return later.

Let us now go back to the Newtonian view and regard force as a fundamental concept. The force that we are most familiar with is the force of gravity. Newton showed that not only the motion of bodies falling to the earth, but the motion of the planets about the sun could be accounted for by assuming that every particle of matter in the universe attracts every other particle with a force proportional to the product of the masses and inversely proportional to the square of the distance between them. This was, of course, no explanation of the force of gravity, and the idea that matter could act upon matter at a distance was distasteful to Newton himself, as it has been almost universally ever since. However, up to about the middle of the nineteenth century it was considered a sufficient goal to attain in a variety of physical phenomena to account for them by means of forces acting at a distance between elements of the system. Particularly in the fields of electricity and magnetism this goal seemed near attainment. There was, however, a very

real difficulty. In the attempt to account, on this principle, for the forces between circuits carrying electric currents, not one, but an infinite number of laws of force between the elements of the circuits was found to answer. Experiment could not decide which was the law of force because experiments could be made only with complete circuits. An end was soon put to the controversy which raged over this question by the publication of Maxwell's Theory of Electricity and Magnetism. In this theory action at a distance played no part. All the forces between electrically charged bodies, between magnetized bodies, the mutual forces between electric circuits and between magnets and electric circuits were ascribed to a system of pressures and tensions in a universal medium which pervaded all bodies and extended throughout all space. And this medium was the same as that which had been previously postulated as the vehicle for the waves of light. The goal in the dynamical explanation of physical phenomena now changed to the attempt to account for them by direct action through a medium instead of by action at a distance. For electric and magnetic effects the idea of action at a distance became unnecessary, but for the commonest force of all—gravitation—it could not be dispensed with. Although the elementary law of gravitational attraction is remarkably similar to the elementary laws of electric and magnetic attractions and repulsions, there are sufficient differences between them to place the force of gravity in a different category from the other natural forces. Gravitational force is always attractive; electric and magnetic forces may be attractive or repulsive; gravitational force appears to be wholly independent of the medium through which it acts; electric and magnetic forces are enormously influenced by the medium. These differences led Maxwell to predict that attempts to account for gravitational force by a system of pressures and tensions in a medium, analogous to those used to account for electric and magnetic forces, would be doomed to failure.

An answer to this riddle of gravitation has been given by Einstein, and this answer has come through the general theory of relativity. The principle of relativity has arisen through repeated failures to detect any influence upon optical phenomena by experiments performed on the earth due to the motion of the earth about

the sun. In the same way, the two principles of physics that have kept their validity—the law of the conservation of energy and the second law of thermodynamics—grew out of the failure to find any violations of them. As is the case with these two laws, the principle of relativity may be stated in a number of alternative ways. From the gravitational point of view Jeans has stated this principle " A planet cannot describe a perfect ellipse about the sun as focus," and this statement expresses very distinctly the failure of the Newtonian mechanics to account for all known physical phenomena.

Now instead of trying to modify Newton's laws of motion, Einstein goes back of them and uses views of space and time which are different from those upon which the Newtonian mechanics is founded. For the purpose of describing natural phenomena the Euclidean space has almost universally been considered sufficient. Whether or not Euclidean space represents anything which has a real existence has been a doubtful question among mathematicians from the earliest times. Other systems of geometry have been developed, following closely the plan of Euclid, keeping some of his axioms and rejecting others, and the consequences examined. Riemann, however, in his essay on the " Hypotheses which are the Foundation of Geometry " introduced a new system of geometry, and the development of Riemann's geometry supplied the altered conception of space and time necessary for the Einstein theory.

The Riemann geometry bears a relation to Euclidean geometry somewhat analogous to the relation of direct action to action at a distance in physics. According to Riemann, space is a three-dimensional continuum, by which is meant that a point in space may be represented continuously by three independent quantities, the coordinates of the point. Riemann considered the more general problem of a continuum in which n independent coördinates are required to specify a point, thus developing an n-dimensional geometry. In order to define the metrical properties of space Riemann assumed that the square of the distance between two infinitely near points is a quadratic differential form of the relative coöordinates of the points, with coefficients not constant, but functions of the coördinates. In Euclidean space it is always possible to choose coördinates—the usual rectangular coördinates—such that the square of

the distance between any two points shall be expressed as the sum of the squares of the relative coördinates of the two points. In the generalized space of Riemann this cannot be done. An analogy will make this distinction clear. A plane in three-dimensional space may be regarded as Euclidean space of two dimensions, for by choosing any rectangular coördinates in it it is possible to express the square of the distance between two points as the sum of the squares of the relative coördinates of the points. A curved surface in three dimensions, however, is non-Euclidean space of two dimensions, for the distance between two points on the surface measured along the surface cannot be expressed in the same way as on a plane. The geometry of curved surfaces in three-dimensional space was developed by Gauss, and Riemann's geometry is an extension of the Gaussian methods to surfaces of a greater number of dimensions. In this way the conception of curvature of space arose, as a perfectly logical development of the easily conceived curvature of a surface. Space of zero curvature is Euclidean space; if the curvature is different from zero, whether constant or varying from point to point, space is non-Euclidean. Measurements on a two-dimensional surface will tell whether the surface is plane or curved—that is, whether it is Euclidean space or not. For by measuring the circumference of a circle drawn on the surface with a known radius, if the circumference is 2π times the radius, the surface is plane. If the surface is curved the result will in general be different. So it might be thought that measurements in our actual three-dimensional space would tell whether our space is Euclidean or not. In fact, Gauss did attempt to test this question by carefully measuring the angles between three distant points, but needless to say he found no departure from Euclidean space.

We must now consider the question of time. Until Lorentz introduced what he called the "local time" in his theory of electrical and optical phenomena in moving bodies, and thus laid the foundation for the theory of relativity, time and space were regarded as wholly independent concepts, at least for the purpose of describing physical phenomena. Our knowledge of the physical universe we obtain by experience, and it is certainly true that no one ever determined a position in space except at a definite time, nor noted a

time except at a definite position in space. It was Minkowski who first clearly stated that to define an event four generalized coordinates are needed—three to define its place in space and one to define its time. The universe thus becomes, in Riemann's sense, a four-dimensional continuum.

The expression for the square of the line element in this generalized space is a quadratic differential form with ten terms. The coefficients in this expression determine the departure of this generalized space from Euclidean space. In order to satisfy the condition for the complete relativity of physical phenomena it is necessary that this line element shall have the same value in whatever system of coördinates it is measured. Now in Einstein's theory these coefficients have more than a purely geometrical significance. They have a dynamical meaning in that they determine the gravitational field. Or to put it in another way, the curvature of space is determined by the presence of matter. At a great distance from all matter this four-dimensional space is Euclidean. The presence of matter gives to space its curvature. We can now see how, for gravitational forces, the goal of the Hertzian mechanics is attained, although in a wholly different way from that contemplated by Hertz. Gravitational forces, according to Einstein, do not exist. Hertz's law of the straightest path has universal validity in this system, but the straightest path may appear to be a curved path because it must be drawn in space which is curved. In the two-dimensional analogue the straightest path between two points on a curved surface is not the straight line connecting the two points, for that line would take us out of our space. The straightest path is the geodesic drawn on the surface between the two points. And so light rays passing close to the sun are not attracted by the sun, but the space through which they pass being curved under the influence of the mass of the sun, the rays follow a curved path in reaching the earth.

Now any theory of this kind to be at all complete cannot stop with explaining away gravitational forces. Electric and magnetic forces, which we have seen differ in their nature from gravitational forces, must also be considered. I can only mention a remarkable

extension by Weyl of the Einstein theory, which is really a logical extension of the Riemann geometry. In Riemann's geometry the scale of measurement is fixed; a line element at one place can be compared directly with a line element at a distance. But in a system of geometry to remain true to the idea of direct action as opposed to action at a distance this assumption appears unwarranted. And so Weyl assumes that the scale of measurement varies from point to point in the four-dimensional universe. This hypothesis results in another differential form which characterizes the metrical properties of space—this time a linear differential form—and Weyl shows how the electric and magnetic state of space can be interpreted in terms of the coefficients which enter into this expression.

All that I have attempted to do in the foregoing is to show what kind of a theory the Einstein theory is; how radically it differs in principle from what we are accustomed to ask for in a physical theory. This theory opens up to the study of natural phenomena a new universe, a universe in which geometry and physics cannot be regarded as independent sciences. This universe is a four-dimensional metrical manifold; physical phenomena are determined by the metrical properties of this universe. There is no reason that I can see why this generalized space of the Einstein theory should not be named " the ether." But giving it a name does not help in understanding its properties, and it is a wholly different ether from that to which we have grown accustomed.

It is interesting to note that the possibility of space having a dynamical property was suggested by Riemann, although it was left for Einstein to develop the consequences of such a conception. In fact, Riemann went farther, and suggested the possibility of space being a discrete manifold instead of a continuum, and this suggestion is of particular interest at the present time in view of the growing importance of the quantum theory which is founded on the idea of discreteness somewhere as opposed to continuity.

The difficulties in understanding the Einstein theory are not so much mathematical difficulties; they arise from the vain attempt to picture to our minds the kind of space required by the theory. We instinctively try to form a model of some mechanism which will

give us a representation of natural phenomena; but according to Einstein the materials we have hitherto used to form such models— our conceptions of space, time and matter—are inadequate. If his theory is to stand we must make a new universe in our minds, a universe in which space and time have an existence only when considered in their relation to matter.

SLAV AND CELT.

By J. DYNELEY PRINCE.

(Read April 22, 1920.)

It has been long recognized that language is not a final test of race; that is, of race in the anthropological sense. It must be remembered, however, that in current usage the word "race" is not employed to indicate the primitive long-heads, short-heads and round-heads of strict anthropology, about which many modern educated people know and care next to nothing, but rather to denote what should be properly defined as "tribal groups," which subsequently developed into "nationalities," and then into political "nations." Such primitive tribal "races" were originally nothing more than groups of families fortuitously speaking the same language or kindred dialects, who were forced together for purposes of mutual protection, or for the purpose of conquest over weaker and richer peoples. Such a tribal nucleus was the beginning of every modern nation-group. It is, therefore, quite obvious that a "pure" race, that is, a race originating from and maintaining a single strain can not be in existence at the present time. In order to determine national trend development, the student of group characteristics must, therefore, refer to environment and the common interests bred by common speech, rather than to skull-shape or other bodily peculiarities which often vary in individuals of one and the same family.

Mutual comprehensibility and the possession of a common hereditary trend are the two most important features of such influential environment. The peoples now termed "Slavs" and "Celts" must consequently be classified each within their own group from the point of view of their respective speech-groups (= influence-groups), and may be studied still more closely by a comparison of the traditions which have given rise to their mental and spiritual characteristics.

It is the thesis of this paper to set forth how Slavs and Celts, although speaking widely varying branches of the Indo-European linguistic family, are nonetheless strikingly similar to each other in habits of mind and expression.

The Slav, in spite of his prominence in the great war, is even yet but little understood by the West. In fact, the majority of Americans do not even know who these people are, nor whence they come. The Slavonic family is essentially a linguistic division. Indeed, the very word "Slav" probably means 'he who can speak intelligibly' from the same root as *slovo* 'word,' in distinction from non-Slavs, who are known as *njemcy* 'dumb ones,' *i.e.*, unintelligible speakers, a term originally applied by Slavs to all foreigners, but now exclusively to the Germans. The derivation of "Slav" from *slava* 'glory' is unimportant, as *slava* itself is probably but a variant of the *slov-slav*-root meaning 'speak, proclaim.' The Slavonic tribes are much more numerous to-day than their congeners the modern Celts.

There are six linguistic divisions of Slavonic speaking nationalities, viz., Russians, who are subdivided into Great Russians, White Russians and Ukrainians (Little Russians); Poles (with Kashubians); Slováks, who extend across the entire northern border of what was Hungary, from the Ukrainian language-line on the east to the Bohemian border on the west; Bohemians (Czechs) embracing also the Moravian population to the south of them, both tribes speaking a distinctly western Slavonic idiom; Serbs and Croats on the south, who differ only in that they write their common speech, the Serbs in the Cyrillic (Russian) and the Croats in the Latin alphabet; and finally the Bulgarians who speak a simplified form of Slavonic and whose dialects extend, not only through political Bulgaria, but also through a large part of Macedonia. To the Serbo-Croats must be added the Montenegrins and also the Slovenes, inhabiting the district just behind Trieste, and, strangely enough, the little linguistic island of Wends in Saxony and Prussia, who, although separated by centuries of isolation from their southern Slavonic cousins, still use a distinctly Serbo-Slavonic form of speech (Sorbian).

These then are the Slavs, and it will at once be observed that

the distinction between them and also their common bond is one of *language* and not of *race*. It may be predicated that language really carries with it a well-marked aura of influence which permeates a people to the very marrow. While language is in one sense merely a vehicle of expression, it also aids thought and directs trends of mind. It would be difficult otherwise to explain the striking similarity of these various Slavonic nationalities to one another, because they come racially from many stocks.

For example, the Bulgarians are really Huns, whose parent tribe in the latter days of the Byzantine empire, swept across southern Russia like a storm and either drove out or dominated the Serbo-Slavs of the Balkan peninsula. The invaders soon lost their original speech and adopted a modified and corrupted form of the local Slavonic idiom which has since developed into the modern Bulgarian language. The Bulgarian is the *enfant terrible* among these nations, selfishly bound up in his own tribe and hating bitterly his neighbors, the Serbs and Croats. The Bulgarian is to this day in his trends and habit of thought, in short, in all but his speech, more of a Hun than a Slav. The Serbs and Croats are also of fairly mixed race, although they are chiefly descended from original Slavonic speaking tribes which came from the north into the Balkans in the sixth Christian century. This clan has always been a strong warrior nation distinguished by its love of reasonable freedom. The Bohemians and Moravians have a very strong Germanic admixture of blood, for which reason they are politically the most stable-minded of the entire family. The Hungarian Slováks cannot boast of a pure Slavonic speaking origin, as they became mixed in early times with Tatar[1] (Turkic) tribes and more recently with their Finno-Ugric Magyar neighbors and former overlords, a double admixture which has given to the Slovák the low forehead and broad features suggestive of non-Indo-European origin. These Slováks are essentially a laboring class, highly industrious, but rather addicted to drink.

The Poles assert that they are the only pure Slavonic stock, but even among them appears the blond Scandinavian and North

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[1] Cf. J. D. Prince, "Tartar Material in Old Russian," *Proc. Amer. Philos. Soc.,* 1919, pp. 74-88.

German type left by the ravages of the Thirty Years War. The Poles possess the most extremely individualized character of all the Slavs. In other words, among them tribal feeling has developed into a real national patriotism which was at first not evident in their history. Welded together into a great European power by the early Jagiello princess of Lithuanian origin, the Poles, as soon as the Jagiello line died out, began unwittingly to plot their own ruin by insisting in their parliament on the principle of the unanimous vote for all measures (*liberum veto*), so that a single member might veto a bill, or even demand an immediate adjournment, which the rest of the Diet was powerless to prevent. During the past century, however, during which this gallant and individualistic nation passed through an ordeal of fire at the hands of Germans, Russians and Austrians, a much deeper spirit of inherent solidarity has shown itself among them, and this, it is to be hoped, may weld Poland once more by internal force into as strong a European influence as she became under the external pressure of the Lithuanian Jagiellos. Strange to say, until recent times, the Poles, unlike their congeners, have never felt the pressing need of a spiritually united Slavia. Naturally hating the Russians, despising the more prosaic Czechs and Slováks, and ignoring the Serbs and Croatians, the Pole has remained, and is unfortunately inclined to remain, splendidly aloof from his Slavonic brethren. In spite of this wilful isolation, Polish characteristics do not differ fundamentally from those of the other Slavs. Finally in this connection, the Serbs and Croatians constitute a strong race, of mixed stock, it is true, but of genuine Slavonic spirit. Touched by Turkish on the east and south and by Magyar on the north and west, this people through centuries of darkness and oppression by Turks, Magyars and Austrian Germans have retained the spirit seen in all Slavia.

The only Celtic tongued peoples extant to-day are the Gaelic speaking Irish, Manks and Highland Scotch and their distant linguistic cousins of Armorican speech, the Welsh and the Bretons of France. The allied Armorican Cornish disappeared as a living language about 1789.[2] These tribes are mutually incomprehensible when using Celtic, for the Gaelic dialects of Ireland and Scotland

[2] H. Jenner, "Handbook of the Cornish Language," London, 1904, p. 21.

and the scanty remnant of Gaelic in Man,[3] although mutually similar to the philologist, are, when spoken, far apart from one another phonetically, while the Armorican idioms, Welsh and Breton, are not only almost incomprehensible to each other, but are divided by a great phonetic and morphological gulf from the Gaelic branch. So here we have people to whom the rule of similarity of language just expounded for the Slav would seem not to apply, and yet these tribes are all strikingly alike in thought and trend of mind, and it is especially noticeable that among the Celts who have lost their original tongues, such as the central French and mid-European Germans, this spirit has practically disappeared. The rule for Slavs and Celts is really the same, although obscured, for in ancient days, the Gaelic Celts of Ireland, Scotland and Man were mutually intelligible, as their educated classes still are, and even the Armorican, whose tongue was once the idiom of all southern Britain, drew from the same linguistic fountain-head as did the Gaels. The fact that the influence still lasts is due to the extreme traditionalism of the Celt who has clung to his ancient tendencies handed down to him in early oral literatures, varying to-day in language, but similar in thought and trend.

What then is the common Slavo-Celtic spirit which seems to connect these two geographically remote Indo-European branches? What force underlies the folk-literature of Slav and Celt alike, inspiring both Slavonic and Celtic music and poetry, with a common fire, showing similar trends in the thought of both peoples, and moulding the individual disposition along closely similar lines?

The underlying similarity seems to be twofold; viz., (a) temperamental discontent, and (b) morbid joy in sorrow.

(a) The most important point in common is perhaps the quality of longing, a passionate desire for the unattainable, which, when reached, shall give perfect joy, in other words, a spirit of restless quest. Thus, the Slavonic religious ideals, demanding intensive, often absurd personal sacrifices, long fasts or arduous pilgrimages

[3] There is hardly a score of people to-day in Man who can converse in Manx. When the writer was in Man in 1897, a Mr. Cashell of Port Erin was almost the only person who could talk Manx fluently. He told me that at that time there were about twenty-five people who had a thorough knowledge of the language.

made under circumstances of enforced privation, similar to the self-inflicted tortures of the Hindu devotees, may be compared with the Celtic fasts and semi-monastic ideals. Mysticism in general is a common bond between the Slav and Celt. Slav and Celt alike seem careless of their success or even survival, so strong is the impelling discontent with the present world. Renan wrote of the unending quest of the Celt the following words which apply equally well to the Slav: "This race desires the infinite, it thirsts for it, and pursues it at all costs, beyond the tomb—beyond Hell itself."[4] The Celtic legend of the quest of the Holy Grail, the mysterious chalice of the Last Supper which was regarded as a physical link between Man and God should be mentioned here. It is highly significant that the Celtic Grail-cup could be found only by a physically sex-pure man, an idea which gave the world the later character of Sir Galahad, unknown in the earlier Grail accounts, a man who "never felt the kiss of love, nor maiden's hand in his."[5] This conception of the necessity of absolute sex-purity exists so strongly among the Slavs that an entire sect, the Russian *Skopcy* have devoted themselves to this ideal by an ordinance requiring voluntary sterilization, which is still rigidly observed. The Celts, apparently, have not been guilty of such a caricature, although some of their ancient monks may have resorted to this method of ensuring continence. The Slavs seem to have nothing so definite in their lore as the quest of the Grail, which the Celts not only sought, but actually found.

(*b*) Accomplishment is not a necessary adjunct to Slavonic "success" and this principle constitutes the second point of resemblance between the Slavonic and Celtic characteristics; a morbid delight in sorrow and especially in failure.

The first thing which strikes the student of modern Russian literature is that scarcely a tale emphasizes the qualities which make for success in the formation of human character. Hardly anywhere in these productions do we find the hero battling his way through difficulties to an eventual success due to his own efforts. Stephen

[4] Cf. "The Celt and the World," by Shane Leslie, N. Y., 1917. The entire work deals with the character of the Celt.

[5] Cf. "King Arthur in History and Legend," W. Lewis Jones, Cambridge University Press, 1911, p. 107.

Graham in his recent work on this point ("The Way of Martha and the Way of Mary," London, 1915) is certainly correct in emphasizing the prevalence of this Russian "Gospel of Incompetence." It would seem as if public sympathy has been at all times, but more especially of recent years, with the unsuccessful, rather than with the successful, hero. Even in the old Russian literature, as exemplified in the "Tale of the Armament of Igor" (1185 A.D.), we find a glorification of the defeat of this prince by the Tatar hordes of the Pólovtsy. That there was, however, a healthier tone in Old Russian is evident from such a work as *Zadonščina,* where the great victory of Dimitri Donskói over the Tatar chieftain Mamai is well sung. Of late years, particularly in the Russian literature of the later nineteenth and twentieth centuries, this same tendency is chiefly conspicuous by its absence. This Russian morbid pleasure in failure is seen also among the other Slavs, although to a less marked extent, as exemplified in such Polish songs as *Nasze skiby nasze lany* or the beautiful Czech dirge *Havlíček* and also in many Serbo-Croatian poems of the sadder style.

The Celts, especially the Irish and Scotch, are remarkable for their delight in a "lost cause" which is expressed in such well-known songs as "Patrick Sarsfield" or the "Wearing of the Green" and the many Jacobite ditties of Scotland. It should be noted, however, that many songs of this style breathe a spirit of defiance or at least of obstinacy which always implies remote hope. No such implication of hope is usual in the corresponding Slavonic poetry. The Celtic morbid pleasure in death and its appurtenances such as funerals and wakes is well recognized. Wakes, known as *pominki* is Russian, are observed all over Slavia in much the same manner as among the Celts. From the purely literary point of view, it is a matter of regret that modern Welsh poetical productions have nearly all been case-hardened by the stereotyped soul-deadening form of the twenty-four meters, a system which inclines to sacrifice everything to alliteration and rhyme. The modern Welsh people have been very largely denaturalized as Celts, so far as their power of expression is concerned, by the rigid forms of Protestantism prevalent in Wales which have tinged the whole of recent Welsh literature with a dull conventionalism, thus driving out almost

entirely the spirit of ancient Welsh poetry.   In spite of this fact, the Welsh and Bretons still love grief as much as any Irishman, but differ widely from the Irish Celt in lacking humor, a lack which is shared by the gloomy temper of the Scotch Gaels.   The Slav, on the other hand, does not lack humor entirely,—witness such modern wits as the exquisite Russian Czechov and the Polish authoress Eugenja Zmijevska, but this quality is commonly regarded as an evidence of lightmindedness and absence of mental poise.   The vast mass of Slavs are temperamental extremists, either bathed in a delicious gloom, or else given over for brief periods to slapstick wit and mad dances which, very temporarily, draw the sad Slav out of his habitual introspection.   A perfect parellel to these ebullitions may be seen in the wild riot of Irish, Scotch and Brenton jigs and reels, a form of music not much countenanced at present by the artificially sobered Welsh.

Old Slavonic literature[6] is full of tales of mythical heroes who performed deeds of daring and feats of supernatural strength, strongly reminiscent of the Irish Finn McCoul.   Such hero-tales are of course common to all the Indo-European peoples and are not a point of particular resemblance between Slavs and Celts.

It is interesting that both the easternmost and westernmost divisions of the peoples who speak Indo-European still retain the ancient strain of unworldliness and mysticism which so noticeably characterizes the religious devotees of the nations who still use the oriental forms of Indo-European.   The stern practicality of the Teuton which has spread abroad through all the Germanic speaking lands and appears in a special form among the Latin speaking Franks is bounded east and west by a cloud of "unreal" thinkers who turn with delight to pessimism and reject success as a mere material benefit.   Upon neither the Slav nor the Celt has the sun of success ever risen, because both Slav and Celt contemn success.   There was a brief period, while Russia was an empire outwardly mighty under largely Germanic direction but rotten at the core with Slavonic apathy, when it appeared as if there might have been an intellectual union between Russia and the lesser Salvonic peoples.

[6] Cf. I. Porfirieff, "History of Russian Literature" (in Russian), Part I, pp. 49 ff.

This was in fact fostered by the Pan-Slavonic movement which sought to teach the non-Russian Slavs to look to Petrograd and Moscow for their national *stimuli*. What might have come of such a movement no one can judge to-day, for with disaster the Russian character crumbled and the great mass of unthinking sheeplike peasantry fell into the hands of those who profess equality but practise coöperative slavery, while the lesser Slavonic peoples have been left to their own devices under the Allied plan of self-determination. It would be rash to prophesy the future of these newly formed states of Poland, Czecho-Slovakia and Serbo-Croatia. Poland alone has a great tradition upon which to build and her people may have developed, as indicated above, a spirit of sufficient solidarity to insure their national life.

Judging the future by the past, however, it would seem as if the Slavs would again[7] be compelled eventually to seek the guiding hand of the stranger, for Slavs and Celts have ever been politically impossible when left to themselves. The temperamental discontent just discussed, common to both peoples, has made them supremely jealous and consequently litigious and fractious in all matters of government. Their tendency is to refuse obedience to leaders of their own nationality and to break up into small partisan groups. Among Russians especially debate is difficult. The Irish "Kilkenny Cats" are as Slavonic as they are Celtic! The fact is that Slavs and Celts are both Oriental. When Sergius N. Syromiatnikoff hinted that Russia had made her great error in turning westward instead of eastward for her ultimate culture, he was fundamentally right.[8] The same idea was frequently expressed by Dostoievsky,

[7] The early Slavs of Russia is summoned the Scandinavian hero Rurik (Hrörekr) and his brothers to rule over them, as they confessed that they could not govern themselves. From the Rurik family were descended the princes of Russia during the first historical period. The Russians have always required force, both under the Kingdom of Moscovy, the most notable figure of which was Ivan the Terrible, and under the subsequent Empire. The present Bolshevik government is one of open force, drafting the people to work at the point of the bayonets of the admirably disciplined and organized "Red" army.

[8] Sergius Nikolayevich Syromiatnikoff, "Experiments in Russian Thought" (in Russian), Book 1, St. Petersburg, 1901. This work is a most interesting exposition of the eastward trend in Russian thought. It has unfortunately not been translated.

particularly in his " Journal of a Writer," the last number of which, January, 1881, contains a most elaborate plea for the Asiatic expansion of Russia in preference to a distinctly western trend. Slavs and Celts are Oriental character-types in Europe requiring the strong hand of western administration to guide them to efficiency. Their thought-basis is from the East and they have never been thoroughly westernized. Full of individual kindliness and charm, lacking the qualities which make for that worldly success which both peoples in general despise, these eastern and western European tribes, if rightly controlled and guided, should be a welcome counterbalance to the too rigid materialism of the Germanic peoples and the cold selfishness of the tribes of the Latin dispersion.

PRODUCTS OF DETONATION OF TNT.[1]

By CHARLES E. MUNROE and SPENCER P. HOWELL.

(*Read April 23, 1920.*)

The behavior of an explosive and the uses to which it may properly be put depend in a large measure on the form of the reaction or reactions it undergoes on explosion and the character of the products of these reactions. Its suitability for use as a propellant, as a bursting charge for shell, or as a blasting charge in demolitions, in land clearing, in mining and in other engineering operations is largely determined by the composition of its products, the rate at which they are evolved, and the temperature they acquire.

Among the explosives used largely during the recent war none more completely demonstrated its value and efficiency for use in H.E. shell, depth and drop bombs, mines and torpedoes, and for demolitions than TNT, either *per se* or, for fragmentation purposes, when mixed with ammonium nitrate or sodium nitrate to form the explosives styled amatol and sodatol. The authors from their investigations of the properties of the various surplus military explosives, which were assembled and being produced in large quantities as the armistice was declared, with a view to their utilization in civil undertakings, gave it as their opinion[2] that TNT, when used as directed, was especially suitable for use in the open. Returns from the National Park Service, Alaskan Engineering Commission, Reclamation Service, Bureau of Public Roads and the College of Agriculture of the University of Wisconsin, to each of which allotments of TNT have been made, and by whom it has been extensively used over a wide extent of area and under most varying climatic conditions, in quarrying, boulder breaking, ditch digging, land clearing and analogous operations, confirm this opinion. It

[1] Published by permission of the Director of the Bureau of Mines.
[2] U. S. Department of Agriculture Circular 94, of 1920: "TNT as a blasting explosive." Charles E. Munroe and Spencer P. Howell.

should however be stated that notwithstanding its excellent qualities the cost of manufacture will probably prevent TNT *per se* being used as a commercial explosive and that its use under the conditions noted above would not have been advised except for the necessity of promptly disposing of it and the lack of available funds to devote to its conversion into a more useful form.

As is pretty generally known, TNT is produced by the nitration of toluene but by such nitration, according to the way it is carried out, a large number of mono-, di- and tri-nitrotoluenes are produced. The existence of six different isomeric trinitrotoluenes is recognized as possible. By the methods now in commercial use the material which is produced in the largest quantity and in a pure, or nearly pure, condition is the α- or symmetric trinitrotoluene, and it is this material that was adopted as a military explosive and to which the distinctive name of TNT has been given. The criterion used for ascertaining the purity of TNT is its setting point after having been melted. Our War Department specifies for acceptance a S.P. of 80° C. for Grade I; of 79.5° C. for Grade II; and of 76° C. for Grade III. Grade I was produced in but small quantity especially for use in booster charges, though some was, perhaps unwisely, specified for demolition purposes.

The chemical reactions which TNT may undergo when exploded will differ with the circumstances under which it is exploded. When TNT is completely detonated unconfined much black smoke is given off, for not only are gases, and perhaps vapors, formed but carbon is set free. A theoretical expression for the reaction of the TNT *per se* is

(1) $\qquad 2C_7H_5(NO_2)_3 \rightarrow 12CO + 5H_2 + 3N_2 + 2C.$
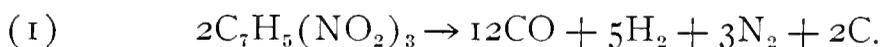
When TNT is completely burned with oxygen the reaction may run as follows

(2) $\qquad 4C_7H_5(NO_2)_3 + 21O_2 \rightarrow 28CO_2 + 10H_2O + 6N_2.$

From the presence of the easily ignitible and readily combustible gases, carbon monoxide and hydrogen, and of free carbon in expression (1) it is apparent that when these substances, in the highly heated condition they must be in at the time of explosion, come in

contact with air they will ignite and burn, though there may not be time for their complete combustion, hence the results of the detonation of TNT in air under ordinary pressure would be represented partly by the first expression and partly by the second.

When the explosion takes place out of contact with air or oxygen in a confined space so that high pressures and temperatures are developed and maintained, the products first formed tend to dissociate or to react with one another to produce new associations so that, dependent on the primary reactions, the pressures and temperatures attained, and the rate of cooling, the kind of products, and the quantities of the several kinds of products will differ from those represented in (1) and (2). One such case may be represented by the expression

$$(3) \qquad 2C_7H_5(NO_2)_3 \rightarrow 12CO + 2CH_4 + H_2 + 3N_2.$$
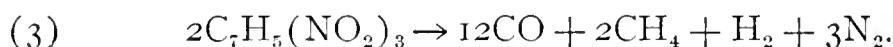
In practice TNT is exploded by a detonator, or, as in H.E. shell, by a primer and booster. Since TNT is less sensitive to detonation than dynamite, gun cotton and the better known high explosives it is advised that a No. 8 mercury fulminate, potassium chlorate detonator be employed to detonate it. Where "weaker" detonators, or those containing less than two grams of the detonant, have been employed to explode TNT in the open the explosive effect of the latter has been less and the smoke given off was grey.

In all cases detonators of some kind are used to explode TNT. They usually consist of copper capsules, which in the form of electric detonators are provided with copper leading wires and resistance bridges sealed in by sulphur plugs, and they are charged with determined weights of mercuric fulminate alone, or mercuric fulminate and potassium chlorate mixed, or mercuric fulminate and a tetryl booster, or with lead azide or other detonant, and on explosion they will give rise to gaseous and other products which will be mingled with the products from the TNT itself. It is true that the weight of the charge of detonant is, as a rule, but a small fraction of the weight of the TNT charge detonated but in any precise investigation of the products of detonation of TNT the products from the detonator used should be taken into account.

Although solid explosives, such as TNT is, when employed for

industrial purposes may be loaded directly into the bore holes yet experience has shown that convenience, economy and safety are promoted by using them in cartridge form. However, it has been demonstrated at the Bureau of Mines Experiment Station that the materials of the cartridge wrapper and the amounts used must be carefully considered since when combustible, as in industrial practice they usually are, they play a part in the reactions taking place on explosion and modify the kind and quantity of the gaseous products. Careful attention is now given to this matter of the wrapper in the preparation of explosives to pass the tests of Permissible Explosives since, by the nature of the tests they must pass, the quantity of inflammable and combustible, and, by regulation, that of the poisonous gases in the product must not exceed a fixed limit, nor may those of the explosive when in use in coal mines if it is desired that the explosive shall keep its place on the list of Permissibles.

Investigations of the products of explosion or detonation of TNT have been made by several observers. The earliest record noted is by C. E. Bichel[3] in his " Table III., 1904," where, in a list of data for a considerable number of explosives, under " Trinitrotoluol " the following products in per cents by weight are given:

	Per Cent.
Carbon monoxide	70.5
Carbon dioxide	3.7
Hydrogen	1.7
Nitrogen	19.9
Carbon	4.2
	100.00

G. Carlton Smith, on page 90 of his book[4] cites the above analysis stating that the products analyzed were " from the complete explosion of the material under atmospheric pressure." Michele Giua[5] cites the same data from Bichel and states " sotto l'azione di un detonatora di fulminato di mercurio (gr. 1.5 di detonatore)"

[3] " New Methods of Testing Explosives," C. E. Bichel. Translated and edited by Axel Larsen. London, 1905.

[4] " TNT, Trinitrotoluenes and Mono- and Dinitrotoluenes; their Manufacture and Properties." New York, 1918, D. Van Nostrand Co.

[5] " Chimica delle sostanze esplosive." Milan, 1919, Ulrico Hoepli.

but neither of these authors state the source from which the information was drawn.

It is probable that the explosion from which the products reported were obtained was carried out in the form of explosion bomb known as Bichel's Pressure Gage which was described and illustrated by Bichel in his paper on "Untersuchung Methoden für Sprengstoffe"[6] and also in the book translated by Larsen as already stated.

Data on the explosion products of trinitrotoluene is also given by Poppenberg and Stephan[7] who made use of a calorimeter bomb. They give the following description of their method of procedure:

The experiment was conducted as follows: The bore hole of a lead bomb was loaded with compressed explosive, and over this was placed a lead plate which fitted exactly, the cap projecting through a hole in the plate. For further tamping the bore hole of the lead bomb was filled with dried sand and the upper part then covered with a lead plate. In several experiments we used a leaden seal, which contained the primer, for tamping. After placing the leaden seal in the bore hole the edge of the bomb was still about 0.5 cm. higher; this was turned over under the steam hammer by means of an apparatus for this purpose, and thus a complete tamping was obtained.

When the porcelain bomb was used for the experiment, we first arranged the tamping with sand and then poured Wood's metal into the conical boring in order to obtain a perfect seal. After this the fuse wire was joined to a very thin, pliable and insulated copper wire, and the bomb, thus prepared, was set inside the large steel bomb with the aid of a wire noose. In order to prevent the lead from being forced into the gas outlet, this had to be covered with an iron plate. The thin copper wires of the fuse were fastened to the bomb-head and this was screwed into the bomb. After an evacuation of about 20 cm. mercury the charge was ignited. During the progress of the work, the temperature of the gases was lowered to such an extent that the silk insulation of the wire was never burned. Therefore it was possible to complete a determination of the carbon given off. The carbon was rinsed out of the bomb so far as possible and then burned to carbon dioxide. It occurred to us to conduct the blasting in the material in which the explosives in question are used, but it did not seem advisable to perform the experiment in this manner, because all other materials, lead and porcelain except, react with the explosion gases. Porcelain alone can be used for explosive compositions which are rich in oxygen, since lead oxidizes. Therefore, it is necessary to dry the bombs before igniting the contents in order to prevent the water from having any effect upon the actual combination.

[6] *Zeitschrift f. Berg-, Hutten- und Salinen-Wesen,* 50, 669–89, 1902.

[7] "Ueber die Zersetzung von Pulvern und Sprengstoffen," *Zeitschrift für das gesamte Schiess und Sprengstoffwesen,* 5, 291–6, 1910.

Following this procedure when the charging density in the bomb was about 0.2 the products of two trials gave respectively the following results on analysis:

	1. Per Cent.	11. Per Cent.
Carbon monoxide	59.01	60.60
Carbon dioxide	1.93	1.66
Methane	1.97	1.90
Hydrogen	20.50	20.80
Nitrogen	16.05	16.08
	99.46	101.04

In a further experiment in which the trinitrotoluene was exploded in a lead cylinder enclosed in the bomb Poppenberg and Stephan obtained

	Per Cent.
Carbon monoxide	46.02
Carbon dioxide	20.60
Methane	1.40
Hydrocarbons	1.08
Hydrogen	7.61
Nitrogen	21.83
Air	1.33
	99.87

In discussing their results Poppenberg and Stephan referring to an opinion advanced by Kast from a study of theoretical equations of decomposition of trinitrotoluene say: " Kast calls particular attention to the fact that no water is formed when trinitrotoluol is detonated; our experience does not correspond to this assertion. We could prove regularly the presence of water in quantities of 1.5 to 1.8 per cent. in the explosion products. According to Kast's equation, 23.4 percent. of hydrogen was to be found in the explosion products, but the analysis shows only 21 per cent. This fact indicates further that when trinitrotoluol is detonated water must be formed."

Relative to the " hydrocarbons " reported these authors say:

The large carbon and hydrogen concentration governs the formation of hydrocarbons, which probably come from previously formed acetylene (compare Pring and gas composition of the explosion products of ammonal). The quantity, 1.08 per cent., is not significant and will not have any real effect on the explosion constants. Whether or not their formation affects the maximum pressure, that is, whether they are formed at the moment of explosion

or not until later, we will leave undecided. When analyzing the gas one naturally has to absorb these hydrocarbons first by means of bromine and fuming sulphuric acid, for otherwise the methane determination will be incorrect. If the explosion gases are lead off through ammoniacal silver solution, a small precipitate is obtained which we claim to be acetylide. Moreover, the explosion gases contain in small quality products of the incomplete combustion, which probably account for their disagreeable sharp odor. We presume, on account of the color of fuchsine sulphurous acid, unsaturated aldehyde.

We found further, in the explosion gases of trinitrotoluol significant quantities of ammonia, about 6 per cent. We ascertained this while we were introducing the gases and the ammonia set free from the residue of the explosion by potash-lye, into standardized muriatic acid. The ammonia could have been formed, as Kast assumes, by direct combination of nitrogen and hydrogen. We are not willing to subscribe to this opinion, for then we should not be able to explain why only insignificant small quantities of ammonia are formed when picric acid is detonated. We are much more of the opinion, supported by Sabatier's experiments, that the ammonia is formed from nitric oxide and hydrogen. The nitric oxide must be formed in quantities which correspond to the equilibrium between oxygen and nitrogen. According to Sabatier[8] $2NO + 2H_2 = N_2 + 2H_2O$ (I). But in the case of greater hydrogen concentration, ammonia is formed, $2NO + 5H_2 = 2H_2O + 2NH_3$ (II). In the case of picric acid only small quantities of hydrogen are contained in the explosion gases, therefore equation I is substantially realized. But in the case of trinitrotoluol the nitrogen present is converted into ammonia. These reactions occur with great speed; whether or not they are to be considered in arriving at the disintegration equation, later experiments will have to prove.

Bichel in his "Table III. of 1904" definitely states that the data presented there is given in percentages by weight. Smith in reporting the analyses of the different products of these experiments treats them as if they were stated all in the same terms whereas the results in the second and third experiments he cites appear to be stated in percentages by volume. Poppenberg and Stephan do not state the terms in which they report their results, evidently assuming that the results of the analysis of a gas will be understood as being given in percentages by volume since this is the usual custom, and an examination of the data justifies this opinion.

Taking the data of Bichel's experiment and subtracting the solid C the percentage by volume of the residual permanent gases under normal conditions may be found. The following result is thus obtained:

[8] *Ann. de phys. et chem.*, 1905, 319.

	Per Cent.
Carbon monoxide	60.32
Carbon dioxide	1.98
Hydrogen	20.65
Nitrogen	17.05

and it is seen that the composition nearly approaches that given for the products of Poppenberg and Stephan's experiments I. and II.

Bichel's experiment is the only one whose results admit of a comparison being made with TNT itself in order to ascertain the extent to which the two agree. For this purpose Bichel's percentages for the compound substances have been reduced to their elements, the total for each element assembled and the elementary composition of the products compared in the following with that of pure TNT.

ELEMENTARY COMPOSITION OF BICHEL'S PRODUCTS AND OF TNT BY WEIGHT.

	Bichel's Products.	TNT.	Difference.
Carbon	35.423	36.990	−1.567
Oxygen	42.977	42.277	+0.700
Hydrogen	1.700	2.219	−0.519
Nitrogen	19.900	18.509	+1.391
	100.000	99.995	

In the descriptions of the above investigations as found no description of the trinitrotoluene used or any means of checking it, such as melting point, setting point or other data appear. Poppenberg and Stephan do not state what kind of detonator was used, Giua notes that Bichel in his first experiment used 1.5 gram mercury fulminate detonator. Experience has shown that at least a No. 8 detonator containing 2 grams[9] of the fulminate charge is essential to insure the full detonation of TNT, and the somewhat erratic results obtained in the pressure gage led us to consider the trial of tetryl detonators in the hope that more certain uniformity might result.

Considering the state of the information regarding the explosion products of trinitrotoluenes that we have found in the literature; the

[9] " A Primer on Explosives for Metal Miners and Quarrymen," Charles E. Munroe and Clarence Hall. Bureau of Mines Bulletin 80, 1915, page 36.

fact that the Bureau of Mines Experiment Station possesses a Bichel Pressure Gage equipment with proper laboratory accessories which it has long made use of in its tests of explosives to determine their " Permissibility " and for other purposes, and a force experienced in their use ; and that TNT is now readily accessible and possesses a special interest, it has been deemed proper to make a special investigation of the products of detonation of TNT. As the investigation will necessarily be somewhat prolonged we are presenting here practically a progress report giving the preliminary results.

The TNT at command from the war surplus gave a solidification point of 80.2°, and a nitrogen percentage by the Orndorff method of 18.14 and by the Dumas method of 18.32 both S.P. and N-content being used as criterions of purity, and the N-content being also used as a ready check on the completeness of the recovery of the products.

The Orndorff method of determining nitrogen devised by Prof. Orndorff of Cornell University and as yet unpublished, is briefly a modification of the Kjeldahl method in which red phosphorus and hydrogen iodide, together in some instances with iodine, is used as the reducing agent, and cupric sulphate, sodium sulphate and sulphuric acid as the digestion agent. This method has been quite generally used during and since the war and is much approved. The method gives quite concurrent results on explosive substances and from general considerations of all the circumstances it is believed to give results to about the same degree below the truth that the Dumas method does above.

The Bichel Pressure Gage equipment of the Bureau of Mines is described, with illustrations, on pages 103–109 of Bureau of Mines Bulletin 15[10] and the procedure followed in its use on pages 30–32 of Bureau of Mines Technical Paper 186.[11] In early tests of explosives detonations were made in lead bombs enclosed in the gage after the manner described by Poppenberg and Stephan but this was found to injure the gage and alter its volume, hence the method was long since abandoned. A recent recalibration of both the 15- and 20-liter

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[10] " Investigations of Explosives Used in Coal Mines," Clarence Hall, W. O. Snelling, and S. P. Howell. 1912.

[11] " Method for Routine Work in the Explosives Physical Laboratory of the Bureau of Mines," S. P. Howell and J. E. Tiffany. 1918.

gages showed their volumes to be 15.3 and 20.6 liters respectively and these latter volumes are made use of here in ascertaining the loading or charging density. It is to be noted that the pressure in the gage is reduced to 50 ± 5 millimeters before the explosive is fired.

Unless otherwise stated a No. 8 electric detonator, containing in its copper capsule 2 grams of composition consisting of mercuric fulminate 80 per cent. and potassium chlorate 20 per cent., was used to detonate each charge of TNT.

As before stated the explosive used was Grade I TNT prepared for the Ordnance Department of the U. S. Army. The material was received in bulk and in preparing it for the gage the weighed charge was packed in a tinfoil wrapper. This tinfoil varied in weight from 1.5 grams on the 25 gram charge to 9 grams for the 400 gram charge of TNT.

The pressure of the permanent gases in the gage was measured on a calibrated Schaeffer and Buddenberg gage 5 minutes after firing the shot, and a differential sample of the gases drawn off over mercury for analysis one half hour after firing the shot, the temperature of the gage and the gases being read at the same time.

In those tests where a charge of 250 grams or more was used, the pressure of the gases was greater than the capacity of the Schaeffer and Buddenberg gage. Accordingly, in order to be able to make a reading, immediately after firing the shot, the gases were allowed to equalize in pressure between the 15-liter gage and a 20-liter gage previously evacuated at 50 millimeter pressure, connected together for that purpose. The observed pressure reading in those tests is the pressure obtained in the two gages after equalization.

The gases were analyzed in the Burrell modification of the Orsat apparatus described as to its construction and operation by Burrell and Oberfall[12] being determined in the order CO_2, O, CO, H, CH_4 and N, and the results of the analyses are presented as determined in percentages by volume.

[12] " The Use of Copper Oxide for Fractionation Combustion of Hydrogen and Carbon Monoxide in Gas Mixtures," G. A. Burrell and G. G. Oberfall. *Jour. Ind. Eng. Chem.*, 8, 228–31. 1916.

CALCULATIONS

A computation of the total amount of nitrogen in the gases compared with the total nitrogen in the explosive, detonator, and residual air in the gage, serves as a check on the accuracy of the observations involved. This computation is based on the following data:

> Analysis of gases,
>
> Weight of charge,
>
> Barometer,
>
> Absolute pressure in gage,
>
> Temperature in gage before shot,
>
> Temperature in gage after shot,
>
> Pressure of permanent gases.

The following complete calculation of test $\dfrac{M-2354}{P-1847}$ is given as an example of the method of calculation:

Analysis of Gases.

	Per Cent.
CO_2	1.1
O	.0
CO	60.2
H	21.0
CH_4	1.9
N	15.8
Weight of charge	300 grams
Barometer reading	732 mm.
Absolute pressure in gage	50 mm.
Temperature of gages before shot,	
(15 liter gage)	25° C.
(20 liter gage)	25° C.
Temperature of gages after shot,	
(15 liter gage)	27° C.
(20 liter gage)	25° C.

Nitrogen in Explosive.

$300 \times .1814 = 54.420$, in which $300 =$ weight in grams of explosive, $18.14 =$ per cent. N in TNT, as determined by the Explosives Chemical Laboratory by the Orndorff Method.

Nitrogen in Residual Air.

(1)

$$\frac{50 \times 15.3 \times .7904 \times 273 \times 1.2542}{760 \times 298} = .908,$$

in which $1.2542 =$ weight of 1 liter of N at 0° C. and 760 mm.,

$$\frac{50 \times 273 \times 15.3}{760 \times 298} = \text{volume of air at 0° C. and}$$

760 mm. left in 15 liter gage.

$79.04 =$ per cent. N in air.

(2)

$$\frac{50 \times 20.6 \times .7904 \times 273 \times 1.2542}{760 \times 298} = 1.223,$$

in which $1.2542 =$ weight of 1 liter of N at 0° C. and 760 mm.,

$$\frac{50 \times 273 \times 20.6}{760 \times 298} = \text{volume of air at 0° C. and}$$

760 mm. left in 20 liter gage.

$79.04 =$ per cent. N in air.

Nitrogen in No. 8 Electric Detonator.

$2 \times .80 \times .0985 = .158$ grams, in which $2 =$ weight of charge in grams, and $80 =$ per cent. mercury fulminate in charge, and 9.85 per cent. N in mercury fulminate.

Total N Put in Gage.

From explosive	54.420 grams
From residual air	2.131 grams
From electric detonator	.158 grams
	56.709 grams

Nitrogen in Gaseous Products of Combustion.

Observed pressure gage reading, 8.05 kg. per sq. cm.	5,925 mm. mercury
Barometer	732 mm. mercury
Total pressure in gages	6,657 mm. mercury

$6657 \times .01832 = 121.96,$
$6657 \times .02483 = 165.29,$ } 287.25 liters of gas from 300 grams explosive, in which $6657 = $ total pressure in gages in mm. of mercury,

$.01832 = $ factor to reduce to $0°$ C. and 760 mm. pressure $\dfrac{273 \times 15.3}{760 \times 300}$

$.02843 = $ factor to reduce to $0°$ C. and 760 mm. pressure $\dfrac{273 \times 20.6}{760 \times 298}$,

$287.25 \times .158 \times 1.2542 = 56.922$ grams N in gases, in which

$287.25 = $ liters of gas in both gages at $0°$ C. and 760 mm.,

$15.8 = $ per cent. N in gas,

$1.2542 = $ weight of 1 liter of N at $0°$ C. and 760 mm.

N put in gage	56.709 grams
N found in gases	56.922 grams
Difference	+.213 grams

In order to compare directly the products of combustion from the explosive at different pressures, all of the gas analyses were computed free from the nitrogen in the residual air and that given off by the electric detonator. These results are given with each test and also in the summary in Table No. 2.

DETAILS OF TESTS.

Test No. $\dfrac{M - 2354}{P - 1834}$.

Weight of charge 25 grams.

Temperature of gage before shot $29°$ C.

Temperature of gage after shot $29°$ C.

Barometer, 728 mm.

Observed gage pressure 1.01 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2	6.2	CO_2	6.4
O	.0	O	.0
CO	51.5	CO	53.2
H	26.1	H	26.9
CH_4	.2	CH_4	.2
N	16.0	N	13.3

Calculations.

N in explosive, 25 × .1814 .... 4.535 grams
N in residual air .... .896 grams
N in No. 8 electric detonator .... .158 grams
    Total N put in gage .... 5.589 grams

N found in gases: Obs. pres. 1.01 kg. per sq. cm. ...... 743 mm.
                 Barometer .... 728 mm.
                 Abs. pres. in gage .... 1,471 mm.

$1471 \times .01820 = 26.77$ liters gas from 25 grams.

$26.77 \times .16 \times 1.2542 = 5.372$ grams N in gas.

N put in gage .... 5.589 grams
N found in gas .... 5.372 grams
    Difference .... —.217 grams

Test No. $\dfrac{\text{M}-2354}{\text{P}-1835}$.

Weight of charge, 50 grams.

Temperature of gage before shot 22° C.

Temperature of gage after shot 23° C.

Barometer, 734 mm.

Observed gage pressure 2.88 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2...............	5.0	CO_2...............	5.1
O...............	.0	O...............	.0
CO...............	52.5	CO...............	53.3
H...............	27.1	H...............	27.6
CH_4...............	.4	CH_4...............	.4
N...............	15.0	N...............	13.6

Calculations.

N in explosive, 50 × .1814 .... 9.070 grams
N in residual air .... .917 grams
N in No. 8 electric detonator .... .158 grams
    Total N put in gage .... 10.145 grams

N found in gases: Obs. pres. 2.88 kg. per sq. cm. ...... 2,120 mm.
                 Barometer .... 734 mm.
                 Abs. pres. in gage .... 2.854 mm.

$2,854 \times .01859 = 53.06$ liters of gas.

$53.06 \times .15 \times 1.2542 = 9.982$ grams N in gas.

N put in gage .... 10.145 grams
N found in gas .... 9.982 grams
    Difference .... —.163 grams

Test No. $\dfrac{M - 2354}{P - 1832}$.

Weight of charge, 75 grams.

Temperature of gage before shot 27.5° C.

Temperature of gage after shot 28.0° C.

Barometer 732 mm.

Observed gage pressure 4.60 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2.............	1.8	CO_2.............	1.8
O.............	.0	O.............	.0
CO.............	58.0	CO.............	58.7
H.............	24.8	H.............	25.1
CH_4.............	.1	CH_4.............	.1
N.............	15.3	N.............	14.3

Calculations.

N in explosive, $75 \times .1814$ .... 13.605 grams
N in residual air .... .899 grams
N in No. 8 electric detonator .... .158 grams
    Total N put in gage .... 14.662 grams

N found in gases: Obs. pres. 4.60 kg. per sq. cm. ..... 3,386 mm.
                Barometer .... 732 mm.
                Abs. pres. in gage .... 4,118 mm.

$4,118 \times .01826 = 75.19$ liters of gas.

$75.19 \times .153 \times 1.2542 = 14.428$ grams N in gas.

N put in gage .... 14.662 grams
N found in gas .... 14.428 grams
    Difference .... —.234 grams

Test No. $\dfrac{M - 2354}{P - 1833}$.

Weight of charge 100 grams.

Temperature of gage before shot 28° C.

Temperature of gage after shot 28.5° C.

Barometer 729 mm.

Observed gage pressure 6.81 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2..............	2.0	CO_2..............	2.0
O................	.0	O...............	.0
CO...............	58.0	CO..............	58.5
H................	25.4	H...............	25.6
CH_4.............	.1	CH_4.............	.1
N................	14.5	N..............	13.8

Calculations.

N in explosive, $100 \times .1814$ .... 18.140 grams

N in residual air .... .899 grams

N in No. 8 electric detonator .... .158 grams

    Total N put in gage .... 19.197 grams

N found in gases : Obs. pres. 6.81 kg. per sq. cm. ..... 5,012 mm.

             Barometer .... 729 mm.

             Abs. pres. in gage .... 5,741 mm.

$5741 \times .01826 = 104.83$ liters of gas.

$104.83 \times .145 \times 1.2542 = 19.064$ grams N in gas.

N put in gage .... 19.197 grams

N found in gas .... 19.064 grams

    Difference .... —.133 grams

Test No. $\dfrac{M-2354}{P-1863}$.

Weight of charge, 150 grams.

Temperature of gage before shot 25° C.

Temperature of gage after shot 26° C.

Barometer 738 mm.

Observed gage pressure 10.83 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO₂.............	1.4	CO₂.............	1.4
O................	.0	O..............	.0
CO..............	58.1	CO..............	58.4
H................	25.6	H..............	25.7
CH₄.............	.5	CH₄.............	.5
N................	14.4	N..............	14.0

Calculations.

N in explosive, $150 \times .1814$ .... 27.210 grams

N in residual air .... .911 grams

N in No. 8 electric detonator .... .158 grams

    Total N put in gage .... 28.279 grams

N found in gases: Obs. pres. 10.83 kg. per sq. cm. .... 7,971 mm.

                 Barometer .... 738 mm.

                 Abs. pres. in gage .... 8,709 mm.

$8709 \times .01838 = 160.07$ liters of gas.

$160.07 \times 14.4 \times 1.2542 = 28.910$ grams N in gas.

N put in gage .... 28.279 grams

N found in gas .... 28.910 grams

    Difference .... +.631 grams

Test No. $\dfrac{M - 2354}{P - 1840}$.

Weight of charge of 200 grams.

Temperature of gage before shot 27° C.

Temperature of gage after shot 28° C.

Barometer 726 mm.

Observed gage pressure 13.79 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO₂.............	1.3	CO₂.............	1.3
O................	.0	O..............	.0
CO..............	59.7	CO..............	60.0
H................	22.8	H..............	22.9
CH₄.............	1.2	CH₄.............	1.2
N................	15.0	N..............	14.6

Calculations.

N in explosive, 200 × .1814 .... 36.280 grams
N in residual air .... .899 grams
N in No. 8 electric detonator .... .158 grams
            Total N put in gage .... 37.337 grams
N found in gases: Obs. pres. 13.79 kg. per sq. cm. .... 10.150 mm.
                Barometer .... .726 mm.
                Abs. pres. in gage .... 10.876 mm.

10876 × .01825 = 198.49 liters of gas.

198.49 × .15 × 1.2542 = 37.342 grams N in gas.

N put in gage .... 37.337 grams
N found in gas .... 37.342 grams
Difference .... +.005 grams

Test No. $\dfrac{M - 2354}{P - 1841}$.

Weight of charge 250 grams.

Temperature of gages before shot 26° C.

Temperature of gages after shot, 15 liter, 28° C.; 20 liter, 26° C.

Barometer 727 mm.

Observed gage pressure 6.69 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2.............	1.5	CO_2.............	1.5
O.............	.0	O.............	.0
CO.............	60.3	CO.............	60.7
H.............	20.6	H.............	20.7
CH_4.............	1.9	CH_4.............	2.0
N.............	15.7	N.............	15.1

Calculations.

N in explosive, 250 × .1814 .... 45.350 grams
N in residual air .... $\begin{cases} .905 \text{ grams} \\ 1.215 \text{ grams} \end{cases}$
N in No. 8 electric detonator .... .158 grams
        Total N put in gage .... 47.628 grams
N found in gases: Obs. pres. 6.69 kg. per sq. cm. ..... 4,924 mm.
                Barometer .... 727 mm.
                Abs. pres. in gage .... 5,651 mm.

$$5651 \times .01826 = 103.17$$
$$5651 \times .02475 = 139.86 \Big\} 243.03 \text{ liters of gas.}$$
$$243.03 \times .157 \times 1.2542 = 47.855 \text{ grams of N in gas .}$$

N put in gage .... 47.628 grams
N found in gas .... 47.855 grams
    Difference .... +.227 grams

Test No. $\dfrac{M - 2354}{P - 1847}$.

Weight of charge 300 grams.

Temperature of gages before shot $25°$ C.

Temperature of gages after shot 15 liter, $27°$ C.; 20 liter $25°$ C.

Barometer 732 mm.

Observed gage pressure 8.05 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2...............	1.1	CO_2...............	1.1
O...............	.0	O...............	.0
CO...............	60.2	CO...............	60.6
H...............	21.0	H...............	21.1
CH_4...............	1.9	CH_4...............	2.0
N...............	15.8	N...............	15.2

Calculations.

N in explosive, $300 \times .1814$ .... 54.420 grams

N in residual air .... $\begin{cases} .908 \text{ grams} \\ 1.223 \text{ grams} \end{cases}$

N in No. 8 electric detonator .... .158 grams

    Total N put in gage .... 56.709 grams

N found in gases: Obs. pres. 8.05 kg. per sq. cm. ..... 5,925 mm.
                  Barometer .... 732 mm.
                  Abs. pres. in gage .... 6,657 mm.

$$6657 \times .01832 = 121.96$$
$$6657 \times .02483 = 165.29 \Big\} 287.25 \text{ liters of gas.}$$
$$287.25 \times .158 \times 1.2542 = 56.922 \text{ grams N in gas.}$$

N put in gage .... 56.709 grams
N found in gas .... 56.922 grams
    Difference .... +.213 grams

Test No. $\dfrac{M-2354}{P-1848}$

Weight of charge 350 grams.

Temperature of gages before shot 15 liter 25° C.; 20 liter 24° C.

Temperature of gages after shot 15 liter 27° C.; 20 liter 24° C.

Barometer 731 mm.

Observed gage pressure 9.48 kg. per sq. cm.

<div align="center">Gas Analyses.</div>

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2.............	1.6	CO_2.............	1.6
O.............	.0	O.............	0.
CO.............	60.5	CO.............	60.6
H.............	20.1	H.............	20.2
CH_4.............	2.3	CH_4.............	2.3
N.............	15.5	N.............	15.3

<div align="center">Calculations.</div>

N in explosive, $350 \times .1814$ .... 63.490 grams

N in residual air .... .908 grams

N in No. 8 electric detonator .... .158 grams

    Total N put in gage .... 64.556 grams

N found in gases: Obs. pres. 9.48 kg. per sq. cm. ..... 6,977 mm.

                 Barometer .... 731 mm.

                 Abs. pres. in gage .... 7,708 mm.

$\left. \begin{array}{l} 7708 \times .01832 = 141.21 \\ 7658 \times .02497 = 190.76 \end{array} \right\} 331.97$ liters of gas.

$331.97 \times .155 \times 1.2542 = 64.535$ grams N in gas.

    N put in gage .... 64.556 grams

    N found in gae .... 64.535 grams

       Difference .... —.021 grams

Test No. $\dfrac{M-2354}{P-1857}$.

Weight of charge 400 grams.

Temperature of gages before shot 15 liter 23° C.; 20 liter 22° C.

Temperature of gages after shot 15 liter 25° C.; 20 liter 22° C.

Barometer 731 mm.

Observed gage pressure 10.79 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2...........	1.5	CO_2...........	1.5
O...............	.0	O...............	.0
CO..............	60.4	CO..............	60.7
H...............	19.8	H...............	19.9
CH_4...........	2.3	CH_4...........	2.3
N...............	16.0	N...............	15.6

Calculations.

N in explosive, $400 \times .1814$ .... 72.560 grams

N in residual air .... $\left\{ \begin{array}{l} .914 \text{ grams} \\ 1.231 \text{ grams} \end{array} \right.$

N in No. 8 electric detonator .... .158 grams

    Total N put in gage .... 74.863 grams

N found in gases: Obs. pres. 10.79 kg. per sq. cm. .... 7,942 mm.

               Barometer .... 731 mm.

               Abs. pres. in gage .... 8,673 mm.

$\left. \begin{array}{l} 8673 \times .01844 = 159.93 \\ 8673 \times .02508 = 217.52 \end{array} \right\} 377.45$ liters of gas.

$377.45 \times .16 \times 1.2542 = 75.744$ grams N in gas.

N put in gage .... 74.863 grams

N found in gas .... 75.744 grams

    Difference .... +.881 grams

TABLE I.

SUMMARY OF GAS ANALYSES AS FOUND IN GAGE, LITERS OF PERMANENT GASES AND NITROGEN CHECK USING ORNDORFF VALUES.

	Wt. of Charge (Grams).				
	25	50	75	100	150
CO_2 (per cent.)	6.2	5.0	1.8	2.0	1.4
O (per cent.)	.0	.0	.0	.0	.0
CO (per cent.)	51.5	52.5	58.0	58.0	58.1
H (per cent.)	26.1	27.1	24.8	25.4	25.6
CH_4 (per cent.)	.2	.4	.1	.1	.5
N (per cent.)	16.0	15.0	15.3	14.5	14.4
Liters of gas................	26.77	53.06	75.19	104.83	160.07
N check (grams).............	−.217	−.163	−.224	−.121	+.631
	200	250	300	350	400
CO_2 (per cent.).............	1.3	1.5	1.1	1.6	1.5
O (per cent.)	.0	.0	.0	.0	.0
CO (per cent.)	59.7	60.3	60.2	60.5	60.4
H (per cent.)	22.8	20.6	21.0	20.1	19.8
CH_4 (per cent.)	1.2	1.9	1.9	2.3	2.3
N (per cent.)	15.0	15.7	15.8	15.5	16.0
Liters of gas................	198.49	243.03	287.25	331.97	377.45
N check (grams).............	+.005	+.227	+.213	−.021	+.881

TABLE II.

Summary of Gas Analyses Calculated Free from Nitrogen in Residual Air and Electric Detonator and Density of Loading.

	Wt. of Charge (Grams).				
	25	50	75	100	150
CO_2 (per cent.)	6.4	5.1	1.8	2.1	1.4
O (per cent.)	.0	.0	.0	.0	.0
CO (per cent.)	53.2	53.3	58.7	59.8	58.4
H (per cent.)	26.9	27.6	25.1	26.2	25.7
CH_4 (per cent.)	.2	.4	.1	.1	.5
N (per cent.)	13.3	13.6	14.3	13.8	14.0
Loading density	$\frac{1}{612.0}$	$\frac{1}{288.1}$	$\frac{1}{185.7}$	$\frac{1}{140.3}$	$\frac{1}{92.72}$
	200	250	300	350	400
CO_2 (per cent.)	1.3	1.5	1.1	1.6	1.5
O (per cent.)	.0	.0	.0	.0	.0
CO (per cent.)	60.0	60.7	60.6	60.6	60.7
H (per cent.)	22.9	20.7	21.1	20.2	19.9
CH_4 (per cent.)	1.2	2.0	2.0	2.3	2.3
N (per cent.)	14.6	15.1	15.2	15.3	15.6
Loading density	$\frac{1}{66.23}$	$\frac{1}{56.87}$	$\frac{1}{42.86}$	$\frac{1}{38.05}$	$\frac{1}{33.25}$

NH_3 in Gaseous Products of Combustion.

Previous investigators of the products of combustion have reported varying amounts of NH_3 gas among the gaseous products of combustion of TNT, one investigator reporting as high as six per cent.

In carrying out these tests, a distinct but not strong odor of NH_3 was always obtained on opening up the gage after the shot. To determine the amount of NH_3 present in the gases, all the gases obtained from a 200 gram charge were passed through a dilute solution of sulphuric acid, and the amount of ammonia determined in this solution.

The test showed that the gas contained 0.034 per cent. of NH_3. This value was that expected as the result of odor tests carried out by the Bureau of Mines which showed that an amount of NH_3 corresponding to 0.05 per cent. gave a strong odor of NH_3.

Effect of Density of Cartridge of TNT on Gaseous Products.

In order to determine whether the density of the cartridge of TNT had any effect on the gaseous products of combustion of TNT,

tests were carried out using a 200 gram sample (M — 2630) of Grade I TNT, containing 18.34 per cent. nitrogen by the Orndorff method, which was obtained pressed to a density of 1.50, and the results obtained compared against a 200 gram sample of M — 2354, which was pressed to a density of 0.86.

The results of the tests are as follows:

Test No. $\dfrac{M - 2354}{P - 1840}$.

Density of cartridge 0.86.

Weight of charge 200 grams.

Temperature of gage before shot 27° C.

Temperature of gage after shot 28° C.

Barometer 726 mm.

Observed gage pressure 13.79 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2	1.3	CO_2	1.3
O	.0	O	.0
CO	59.7	CO	60.0
H	22.8	H	22.9
CH_4	1.2	CH_4	1.2
N	15.0	N	14.6

Calculations.

N in explosive, 200 × .1814 .... 36.280 grams

N in residual air ....   .899 grams

N in No. 8 electric detonator ....   .158 grams

    Total N put in gage .... 37.337 grams

N found in gases: Obs. pres. 13.79 kg. per sq. cm. .... 10,150 mm.

                 Barometer ....   726 mm.

                 Abs. pres. in gage .... 10,876 mm.

10876 × .01825 = 198.49 liters of gas.

198.49 × .15 × 1.2542 = 37.342 grams N in gas.

    N put in gage .... 37.337 grams

    N found in gas .... 37.342 grams

        Difference .... +.005 grams

Test No. $\dfrac{M - 2630}{P - 1877}$.

Density of cartridge 1.50.

Weight of charge 200 grams.

Temperature of gage before shot 25° C.

Temperature of gage after shot 26° C.

Barometer 718 mm.

Observed gage pressure 13.51 kg. per sq. cm.

Gas Analyses.

As Found in Gage.		Calculated Free from N in Residual Air and Elec. Detonator.	
	Per cent.		Per cent.
CO_2..............	0.9	CO_2.............	0.9
O................	.0	O...............	.0
CO..............	59.1	CO..............	59.4
H...............	23.5	H...............	23.6
CH_4.............	1.2	CH_4.............	1.2
N...............	15.3	N...............	14.9

Calculations.

N in explosive, 200 × .1834 .... 36.680 grams

N in residual air .... .914 grams

N in No. 8 electric detonator .... .158 grams

Total N in gage .... 37.752 grams

N found in gases: Obs. pres. 13.51 kg. per sq. cm. .... 9,943 mm.

Barometer .... 718 mm.

Abs. pres. in gage .... 10,661 mm.

10,661 × .01838 = 195.95.

195.95 × 15.3 × 1.2542 = 37.601.

N put in gage .... 37.752 grams

N found in gas .... 37.601 grams

Difference .... —.151 grams

TABLE III.

COMPARISON OF RESULTS SHOWING EFFECT OF DENSITY OF CARTRIDGE.

	Sample M-2354	Sample M-2630.
Density of cartridge	0.86	1.50
Weight of charge	200 grams	200 grams

ANALYSIS OF GASES.

(1) *As Found in Gage (Per Cent.).*

CO_2	1.3	0.9
O	.0	.0
CO	59.7	59.1
H	22.8	23.5
CH_4	1.2	1.2
N	15.0	15.3

(2) *Calculated Free from N in Residual Air and Electric Detonator (Per Cent.).*

CO_2	1.3	0.9
O	.0	.0
CO	60.0	59.4
H	22.9	23.6
CH_4	1.2	1.2
N	14.6	14.9
Absolute pressure in gage	10,876 mm.	10,661 mm.
Liters of gases	198.49	195.95
Nitrogen check	+.005 gms.	—.151 gms.

It will be noted from the above comparison that for equal weight of charge, the density of cartridge has no effect, within the experimental error, on the gaseous products of combustion of TNT.

EFFECT OF DIFFERENT PRIMING SUBSTANCES ON PRODUCTS OF COMBUSTION OF TNT.

In carrying out these tests, occasionally samples of gas were obtained using the same weight of charge which gave widely differing results from the usual results. As an example, there are given below three different analyses using a 400 gram charge.

	(1) M-2354 P-1849	(2) M-2354 P-1857	(3) M-2354 P-1855
	Per cent.	Per cent.	Per cent.
CO_2....................................	1.7	1.5	1.7
O.......................................	.0	.0	.0
CO......................................	60.5	60.4	57.9
H.......................................	19.3	19.8	23.6
CH_4....................................	2.4	2.3	1.9
N.......................................	16.1	16.0	14.9
Liters of permanent gases..............	378.21	377.45	411.33

It was thought that these different analyses were the result of the explosion reaction following different courses, and that if a priming charge different from mercury fulminate-potassium chlorate were used for initiating the detonation, the explosion reaction might either be made to always follow the same course or that a still different reaction might take place. Accordingly, tests were carried out using an electric tetryl detonator (M — 2664) containing a base charge of 1.2149 grams tetryl and a priming charge of .4650 grams mercury fulminate-potassium chlorate mixture.

The following table shows the composition of the gases obtained from 200 gram samples of M — 2354 at a density of 0.86 and 200 gram samples of M — 2630 at a density of 1.50, using both a fulminate and tetryl electric detonator. For comparative purposes, all these analyses have been computed free from the nitrogen in the residual air and electric detonators.

Test No.	Sample M-2354.		Sample M-2630.	
	P-1840.	P-1888.	P-1878.	P-1887.
Density	o 86.	0.86.	1.50.	1.50.
Detonator	Fulminate.	Tetryl.	Fulminate.	Tetryl.
CO_2	1.3	1.5	1.2	0.9
O	.0	.0	.0	.0
CO	60.0	60.3	59.7	59.0
H	22.9	22.2	22.9	23.3
CH_4	1.2	1.8	1.2	1.7
N	14.6	14.1	15.0	15.1

It will be noted from the above table that the gases given off by the two samples of TNT were practically the same whether fulminate or tetryl detonators were used.

SOLID PRODUCTS OF COMBUSTION FROM GRADE I TNT.

On opening up the Bichel gage after firing a charge of TNT, there is found deposited on the walls of the gage a very finely divided deposit of black soot-like appearing solid. This same solid can always be observed when TNT is detonated where the smoke can be seen.

The question has arisen as to the amount and composition of this deposit and its effect on the gases, *i.e.,* whether this carbon-like de-

posit would absorb a sufficiently large quantity of gases to influence the observed pressure reading for total quantity of gas produced, or absorb a selected gas in sufficiently large quantity to affect the composition of the gases.

On account of the rough and pitted condition of the interior of the Bichel gage, it was impossible to obtain an exact determination of the amount of this deposit. But several determinations were made to secure this as accurately as possible, and it was found that with 200 grams of M — 2354, 11 grams of solids were obtained, while from 400 grams, 15 grams were obtained, corresponding to 5.5 and 3.75 per cent. respectively. Two determinations made with 200 grams of M — 2630 gave 16 and 18.5 grams or 8.0 and 9.25 per cent. respectively.

While an insufficient number of tests have been carried out to warrant any definite conclusions, it would appear that the amount of deposit decreases with the increase in charge and is increased by the density of the cartridge, as in sample M — 2630 which was compressed to 1.50.

The exact composition of this deposit has not been determined as yet, for this deposit is contaminated by the iron from the support, copper and sulphur from the electric detonator, and tin from the wrapper holding the TNT, and no method so far tried has served to separate them. An analysis of the contaminated deposits has given the following result:

	Per Cent.
Moisture	0.25
Ash	77.10
H	.33
C	34.34
N	1.01
S	3.97
O	.0

As the carbon, hydrogen and nitrogen are the elements in the deposit arising from the TNT, this analysis is recalculated eliminating the contaminating substances, and is as follows:

	Per Cent.
H	1.03
C	96.07
N	2.90

In order to determine the nature and the quantity of gases absorbed by the solid products of combustion, two 400 gram charges were detonated in the Bichel gage.

$$\frac{M-2354}{P-1849}.$$

Time.	Water.	Time.	Water.
9:44:30	0.0	59 :00	6.6
9:47:30	13.0	59 :30	6.6
9:52:30	14.0	10:00 :00	0.0
53:30	14.0	10:00 :30	3.3
54:30	14.0	01 :00	3.3
55:30	14.0	01 :30	3.3
56:00	0.0	02 :00	3.3
56:30	5.0	02 :30	0.0
57:00	6.4	03 :00	1.2
57:30	6.5	03 :30	1.3
58:00	6.5	04 :00	1.3
58:30	6.6	04 :30	1.3

1. After the differential sample of gas had been taken and the pressure in the gage was zero as shown by a water manometer, the gage was again closed up and readings taken every 30 seconds until the manometer reading was constant, when the pressure was again released and the readings repeated. The readings are given in the preceding table.

2. After the differential sample (a) had been taken for analysis and the pressure reduced to zero, the gage was again closed up and readings taken until there was no further increase in the pressure reading on the water manometer, when a second sample (b) of gas was taken and analyzed. The readings on the water manometer and the analyses of the two samples of gas (a and b) are given in the following tables on page 222.

In comparing the two gas analyses, it must be kept in mind that the amount of gas given off by the solid products of combustion was enough to change the analyses of all the gas remaining in the 15.3 liter gage to the extent given above.

When the gage was opened up, the solids in gage were collected and treated in a vacuum extraction apparatus to determine the composition of the gases still retained by these products. In calculating the analysis of the gas in the solids, the oxygen present was used as

$$\frac{M-2354}{P-1855}.$$

Time.	Water, Cm.	Time.	Water, Cm.
9 : 50 : 00........	0.0	10 : 04 : 00.........	14.1
51 : 00........	6.5	04 : 30.........	14.2
52 : 00........	8.5	05 : 00.........	14.5
52 : 30........	9.0	05 : 30.........	14.6
53 : 00........	9.6	06 : 00.........	14.7
53 : 30........	9.9	06 : 30.........	14.9
54 : 00........	10.7	07 : 00.........	15.0
54 : 30........	10.9	07 : 30.........	15.0
55 : 00........	11.3	08 : 00.........	15.2
55 : 30........	11.6	08 : 30.........	15.3
56 : 00........	11.7	09 : 00.........	15.4
56 : 30........	11.9	09 : 30.........	15.5
57 : 00........	12.0	10 : 00.........	15.6
57 : 30........	12.2	10 : 30.........	15.7
58 : 00........	12.4	11 : 00.........	15.8
58 : 30........	12.8	12 : 00.........	15.9
59 : 00........	12.9	13 : 00.........	16.1
59 : 30........	13.0	14 : 00.........	16.3
10 : 00 : 00........	13.1	15 : 00.........	16.4
00 : 30........	13.3	16 : 00.........	16.6
01 : 00........	13.5	19 : 00.........	17.0
01 : 30........	13.6	38 : 00.........	18.5
02 : 00........	13.7		
02 : 30........	13.8		
03 : 00........	14.0		
03 : 30........	14.1		

Gas Analyses.

	a Per Cent.	b Per Cent
CO_2	1.7	2.7
O	.0	.0
CO	57.9	57.9
H	23.6	23.3
CH_4	1.9	1.9
N	14.9	14.2

the basis of determining the air content of the bottle and gases. This determination showed that each gram of solid products in the gage, including the iron, copper, tin and sulphur from the support, electric detonator and cartridge, retained 6.11 cubic centimeters of gas having a composition of:

	Per Cent.
CO_2	71.3
O	.0
H	.0
CO	.0
CH_4	1.0
N	27.7

A careful examination of the pressure reading on the water manometer, analysis of the second sample of gas, and the analysis and amount of gases retained in the solid products shows that the amount of gas retained by the solid products is not sufficient to have any important effect on the observed pressure reading or analysis of the gases.

THE REEFS OF TUTUILA, SAMOA, IN THEIR RELATION TO CORAL REEF THEORIES.

By ALFRED GOLDSBOROUGH MAYOR.

(Read April 22, 1920.)

The Island of Tutuila, American Samoa, is purely volcanic, no elevated limestones having been observed upon it. As has been shown by Daly the exposed volcanic rock is in most places weathered to its ultimate degree, but this does not apply to the region of the southwestern shore between Tafuna and Sail Rock, where a lava flow occurred in times so recent that its surface still shows a ropy structure, while sharp-edged cracks and numerous lava caverns remain open quite as they were at the time of their formation.

The Island is strongly cliffed by the sea, some of these cliffs as at Round Bluff being fully 300 feet high. After forming these cliffs the sea level sank so as to expose a platform of hard volcanic rock which projects from 50 to 250 feet seaward from the foot of the basaltic promontories. The recent lava flow between Tafuna and Sail Rock overwhelmed this platform but elsewhere practically every promontory of the Island shows this old emerged shore-shelf, and remnants of it appear in numerous places lying off shore within the bays, such as in Afonu, Vatia, Fagasa, Leone and Pago Pago harbors, and especially along the south coast between Breaker Point and Fagaitua Bay. It is also found around the off-lying island of Aunuu southeast of Tutuila.

The bays of Tutuila are in regions of fragmentary material and are flanked by ridges of harder rock. Thus the emerged shore platform has resisted erosion where it is composed of basalt as at the spur ends, but has largely disappeared within the harbors where the rocks are generally soft.

A similarly elevated shore-shelf of volcanic rock is found around the islands of the Manua Group, Ofu, Oloosega and Tau, and also at Rose Atoll where it is of hard dolomitized limestone bearing

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corals.   As this shore bench is identical in elevation in these sepa-
rated islands of differing ages and histories, Daly is justified in
the inference that it indicates a relatively recent subsidence of sea
level rather than an elevation of the Islands.   Indeed a relatively
recent emergence of about 8 feet above high tide level is shown by
the Atolls of the Paumotos, and Ellis Groups, as well as by the
islands in Torres Straits, and the southern shore of Papua in the
region of Port Moresby.   It appears also in the Florida Keys and
the Bahamas, and A. Agassiz, 1903, Proc. Royal Soc. London, Vol.
71, p. 413, says that "Throughout the Pacific, the Indian Ocean,
and the West Indies the most positive evidence exists of a moderate
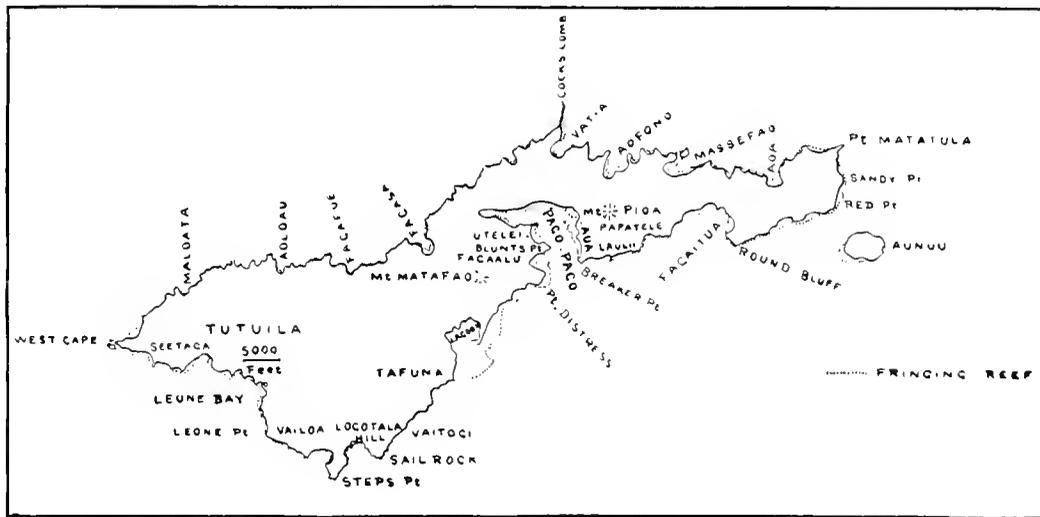
FIG. 1.   Tutuila, American Samoa.   Showing fringing reef now growing
    around the Island in places where the submarine slopes are not too steep.

recent elevation of the coal reefs."   Indeed Daly records a mod-
erate recent emergence of the land along many thousand miles of
coast line not only in the tropical, but also in colder regions.

In the volcanic islands of American Samoa there are no traces
of elevated coral reefs, or limestones except small fragments thrown
up by volcanic action and imbedded in ejected volcanic ash as at
Aunuu, or in a crater rim south of Logatala Hill, Tutuila, or each
of Faleasau Village on Tau Island.

No corals or limestones are found imbedded in or resting upon
the emerged shore bench around Tutuila; nor were any ancient
corals tossed up by storms on the beaches of the inner parts of the

ancient harbors although such would have been the case were coral reefs growing along the shores at the time when this emerged bench was at sea level. Moreover, in places as at Fagatoga this old shore bench was partially covered by talus sliding down from the cliffs, but upon digging this talus away no elevated corals or limestones were found. We are thus forced to conclude that during the time when the sea was at its highest level and cut the now emerged shore-bench, there were no coral reefs growing around Tutuila.

The fringing reef which is now growing outward from the shores around Tutuila, in places where the slope is not too steep, is of modern origin. It is 300 to 1,000 feet wide in places where the underlying volcanic slope is gentle, and is narrow, or absent in places where the submarine slopes are steep as off the seaward ends of the basaltic promontories. Thus the reefs now growing outward over the gentle, wave-worn slopes of the drowned valleys are wider than those off the cliffed promontories at the mouths of the harbors, and everywhere the width of the reef is a factor of the steepness of its underlying volcanic substratum.

The fact that narrow reefs are found on steep submarine slopes and wide ones on gentle slopes was pointed out by Darwin in " Naturalist's Voyage around the World," 1873, p. 472 ; also A. Agassiz, 1903, *Proc. Royal Soc.,* Vol. 71, p. 414, says that the absence of coral reefs in the Marquesas Islands is due to the steepness of their slopes.

Tutuila is very ancient according to Daly, who has made a survey of its lithology (Year Book of the Carnegie Institution No. 18, 1919). Indeed it shows clear evidence of considerable subsidence, the harbors of its northern coast such as Fagasa, Vatia, Afono, Massefau and Aoa being typical drowned valleys, while Pago Pago Harbor, according to Daly, shows characteristics of a drowned valley but has had a complex history.

W. M. Davis (1918, *Bulletin U. S. Geological Survey,* p. 523) observed that the data for the unpublished Hydrographic Office Chart of Tutuila " reveals the existence of a submerged platform from one to three miles in width and from 30 to 50 or more fathoms in depth," and also that " the outer part of the platform is usually somewhat shallower than at half distance off shore as if a poorly developed barrier reef enclosed it."

I find upon contouring this chart (Fig. 2) that it indicates that Tutuila was once surrounded by a wide barrier reef and that also a well-developed fringing reef extended out from the shore and fused in many places with the barrier reef, obliterating the lagoon between them. This fusion of the two reefs was well seen along the north coast between Vatia and Maloata, but it occurred also on the south coast off Cocoanut Point. The lagoon between the barrier and the fringing reef of the southern coast of Tutuila was in many places at least 20 fathoms deep; but along the north coast between Vatia and West Cape it was shallower and was thus largely
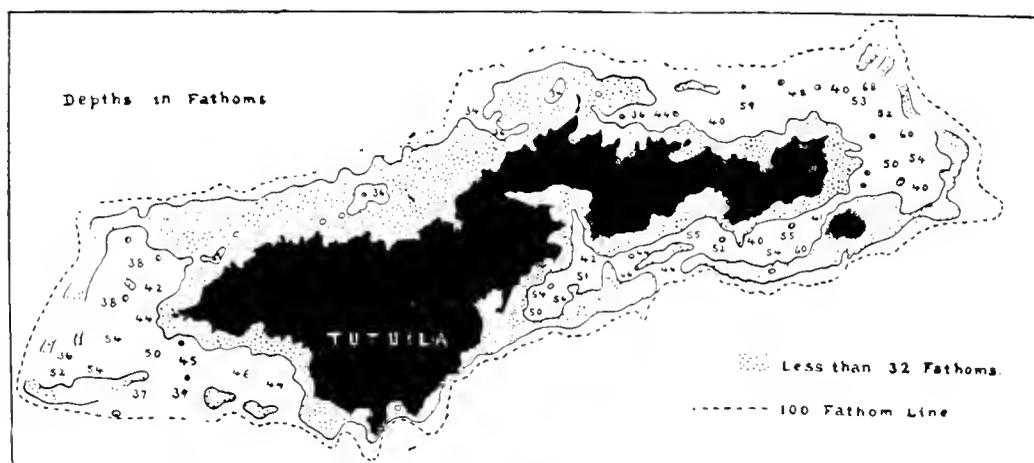
FIG. 2. The dotted areas show the ancient barrier and fringing reefs which once surrounded Tutuila but are not submerged about 190 feet below sea level.

obliterated by the fusion of the fringing reef with the barrier, for the lagoon between these reefs was in most places not more than 2 to 4 fathoms in depth.

As was suggested by Daly this greater depth of the lagoon along the southeastern shore indicates that there was an actual subsidence of the island itself, the southeastern coast sinking more than the northern shore: At any rate these ancient barrier and fringing reefs are now submerged to a depth of about 30 fathoms. As reef-building corals can grow only sparingly at depths greater than about 18 to 20 fathoms, these ancient reefs are drowned and in most places are probably not at present growing upward. In many parts of the Taema and Nafanua Banks, however, the depth is now less than 18 fathoms and modern corals are growing in patches in

such places, but the coral heads are small, and the spaces between them usually wide. In places where the depth is as great as 8.5 fathoms, corals such as *Acropora arcuata* are not more than one foot wide, whereas this species attains a diameter of three or four feet in water not more than 2 to 4 fathoms in depth.

These ancient reefs of Tutuila may have been drowned too suddenly to permit coral growth to maintain them at the surface, or as seems more probable, conditions may for long periods of time have been unfavorable for corals, thus permitting a gradual subsidence or a slow rise of sea level to effectively drown the reefs under a depth too great to permit the renewal of coral growth when conditions became otherwise favorable.

Moreover, we know from observation made at Tortugas, and from those of Wood Jones at Cocos Keeling that a coral reef once killed may not renew itself in half a century. At Tortugas the *Acropora muricata*, which constituted wide areas of shallow reef, were killed by the " dark water " of October, 1878, and even to-day (1920) it is a rare coral over the flats where once it was the dominant species ; and very similar conditions are described by Wood Jones in his " Coral and Atolls " for the lagoon of Cocos Keeling.

Moreover, there are many places along the shore of Tutuila as at Vatia, or near Fagaalu, where corals which once grew upon the reef flat were torn loose and driven ashore by an unrecorded hurricane which must have occurred more than fifty years ago, yet these reefs have not recovered and are quite smooth and devoid of coral heads.

It appears that a reef once established can readily maintain itself, but once it be destroyed many years may elapse before corals can again attain a foothold. Thus on steep slopes if corals which die or are broken off roll down into water too deep for coral growth, a reef may be greatly hindered in establishing itself, and thus one may have the condition seen in the Marquesas Islands where numerous scattered coral heads are found growing upon the submarine volcanic slopes, but they have not yet succeeded in establishing reefs. Coral reefs can readily form upon relatively flat submerged or subsided platforms but steep slopes are unfavorable for their initiation and maintenance.

A study of the submarine slopes of the fringing reefs of Tutuila was made by casting out an anchor upon the seaward edge of the reef, and then steaming seaward in the launch keeping the anchor-line taut and making soundings at distances of 25, 50, 75, 100 feet, etc., from the edge of the reef. This enabled us to determine the slopes as shown in Fig. 3, which represents the conditions seen in various parts of Pago Pago Harbor. The vertical and horizontal scales are the same in these diagrams. We see that the growing edge of the reef usually overhangs at sea level, due to the dense clustering of the rapidly growing *Acropora leptocyathus* in this region, and to the fact that when they die these corals are maintained in place by the overgrowth of lithothamnion. Under this
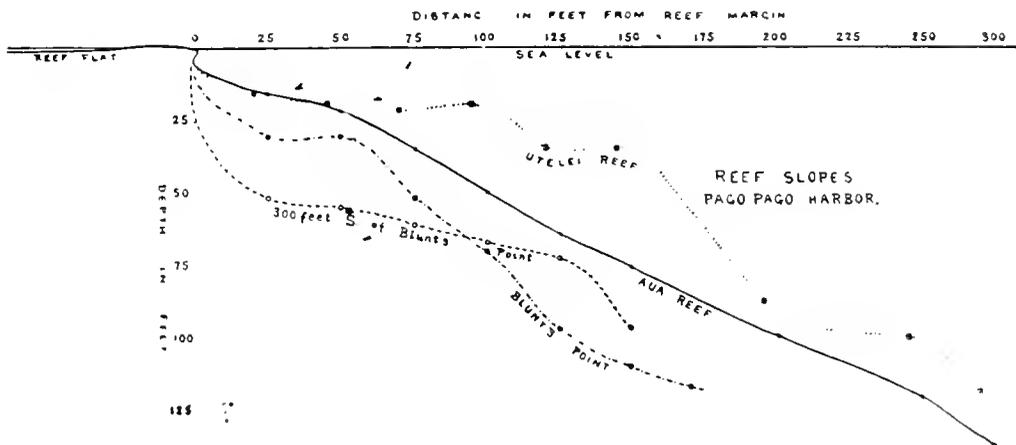
Fig. 3. Submarine slopes off the seaward edges of reef flats of Tutuila.

overhanging edge there is a submarine precipice of usually 5 to 25 feet in depth, beyond which there is a narrow region which is relatively flat, and where corals grow vigorously but cannot reach the surface, due to the surges of the breakers which fracture their stems in time of storm. Beyond this lies the seaward slope composed chiefly of loose dead and alive coral fragments, the talus of the reef, which extends downward at an average angle of about 25° to 30°, thus being somewhat steeper than the average subaërial slopes of volcanic islands. As this talus sets itself at an angle of repose of 25° to 30° it would seem that a slope steeper than this would be unfavorable for the starting of a coral reef, for whenever a coral died or was broken off it would roll down the slope; and new

corals are slow to gain a foothold except in the immediate vicinity
of densely clustered living coral heads.

The inner ends of the bays of Tutuila were partially filled in by
delta-plains when the sea stood higher than at present, but these
have shared in the general emergence of about eight feet, and thus
their swamps were drained, only a few small recent mangrove
swamps being now found as at Massefau, Leone, Vatia, and several
places along the shore of Pago Pago Harbor, as at Aua and Utelei.

During the past fifty years or more, no severe hurricanes have
passed over Tutuila, but there is abundant geologic evidence of their
presence in recent times. Thus the reef flats near the mouth of
Pago Pago Harbor bear many large erratic coral masses which have
been torn off from the edges and tossed up upon the platform of
the reef. One of these fragments at the edge of the reef off the
southern end of Aua village in Pago Pago Harbor is so large that
the Harbor chart records it as " Coral Block 3 ft." Also at Vatia,
Laulii, and many other places, there are masses of recently broken
coral driven up 10 feet above high tide level and now lying cov-
ered with moss under the dense shade of the largest forest trees
which have grown over them since the hurricane tossed them up
as wreckage upon the desolated shore. In ancient times we see
that Tutuila was partially surrounded by a barrier reef which
had grown upward along the seaward edges of a platform of
marine erosion which had become submerged by the subsidence
of the island itself. Fringing reefs were at the same time grow-
ing outward from the shore and in many places, especially along
the northern coast had fused with the barrier reef. Then due
to a rising of the sea level combined with continued subsidence of
the land mass these old reefs were drowned, and for a long period
we find the island unprotected by any reefs while the sea cliffed the
shores not only at the promontories but well within the drowned
valleys. Finally the sea level sank about 20 feet below its highest
level and after this, in modern times, a fringing reef began to grow
outward from the shores and has now attained a maximum width
of not over 1,000 feet. Also in modern times coral patches began
to grow upward upon the Taema and Nafanua Banks in places
which were probably islands well above sea level at the time when

the ancient barrier reef was formed and were thus covered with less than 20 fathoms of water when reefs began again to grow around Tutuila.   These reef patches have now approached to within 6 or 7 fathoms of the surface in a few places.   The average width of the old drowned barrier reef was quite 2,500 feet, and thus, if the growth rate of corals has remained unchanged, it probably existed around the island for a longer time than has sufficed to form the present fringing reefs of Tutuila.   The ancient drowned reefs around Tutuila indicate that fringing reefs did not become transformed into barrier reefs in the manner postulated in Darwin's Theory but contemporary fringing reefs grew outward and fused with the barriers which were formed *in situ* along the seaward edges of the submerged platform.

In formulating his subsidence theory of the supposed sequence of fringing reefs, barrier reefs and atolls, Darwin failed to consider certain factors which are now well recognized.   For example, his theory, as he advanced it, presupposes subsidence of the land rather than an elevation of sea level, nor did he consider the effects of cliffing of shores, the making of platforms of marine planation, or the drowning of valleys upon which Davis lays constant emphasis. To his mind coral growth was probably continuous throughout long periods.   Just what relations if any existed between periods of glaciation and periods of poor development of coral reefs is as yet obscure even in the Atlantic.   Thus Vaughan (1919, *U. S. National Museum Bulletin* No. 103, p. 226, etc. ; also, 1918, *Bull. Geol. Soc. America,* Vol. 29, p. 629) shows that in the West Indian-Florida region there was a maximum development of coral reefs in the middle Oligocene, which was a period of maximal submergence in this region, and at which time the Atlantic and Pacific were connected.   In the Miocene and Pliocene only poor reefs were developed, no Pliocene reefs being known from the West Indian Islands.   Later in Pleistocene and recent times there has been an extensive growth of coral reefs. According to Vaughan in the Oligocene fifteen genera of corals found at present only in the Pacific and Indian region were growing in the West Indies.   Such genera were *Pocillopora, Pavona, Favites, Goniopora, Goniastrea, Galaxea, Stylophora,* and *Alveopora,* and seven others ; but they disappeared from the West Indian reefs

before Pliocene times (Vaughan, T. W., 1917, *U. S. Geological Survey, Professional Papers*, 98 T, pp. 355–376). According to Daly, coral growth was retarded during periods of *lowered* sea level and coincide with periods of glaciation when water was taken out of the oceans to constitute the continental ice sheets; but in Tutuila we have evidence that at the time of *highest* ocean level coral reefs did not grow around the island.

However, Ulrich (1920, *Journal Washington Acad. Sci.*, Vol. 10, pp. 57–78) states that the pressure of an ice sheet may depress the level of the interior of a continent, and this movement tends to be compensated by an elevation in the strand-line. Thus the rise in the continental shelf and of the coastal waters may more than compensate for the water taken out of the ocean to form the ice sheet, and there may even be a rise of sea level at a time when continental land areas are glaciated.

Unfortunately we as yet know practically nothing of the geologic ages of the ancient elevated reefs of the Pacific and have as yet no means for ascertaining their relation in time to those of the tropical Atlantic.

Guppy (1890, *Trans. Victoria Institute*, Vol. 23, p. 60) held the opinion that the corals of the Great Barrier reef were growing on the seaward edges of a submarine plateau, and Andrews (1902, *Proc. Linnean Soc. New South Wales*, Part 2, pp. 145–185) shows that the submerged continental shelf along the coast of Queensland extends southward into the temperate regions, and that the more or less detached coral patches which form the Great Barrier Reef could not have formed the platform but merely grew here and there along its seaward edge after the platform was submerged, and conditions became favorable for coral growth. Indeed as I observed in 1913 the Barrier Reef ceases at the Murray Islands, while the platform upon which it is growing extends northward to the shores of New Guinea, but corals cannot grow in this region due to the mud discharged from the Fly and other great rivers of Papua. Thus this platform extends both northward and southward beyond the limits of coral reef growth. Alexander Agassiz held the opinion that the modern reefs of the Pacific were growing unconformally upon the ancient limestone platforms and ledges.

Vaughan (1914, *Journal Washington Acad. Sci.,* Vol. 4, pp. 26–34) showed that the platform upon the seaward edges of which the Florida reef is now growing, extends northward into a region too cold for coral growth.   Moreover, the disconnected coral patches which rim the seaward edges of the Great Bahama Bank are many of them growing not at the extreme edge of the bank but at an appreciable distance inward from its seaward margin.   The hard-rocky floor of this bank is covered with a layer of flocculent cal-careous mud which when the water is agitated becomes churned into a milky mass fatal to coral growth   Thus coral heads can very rarely attain a foothold excepting near the seaward edges of the bank where pure ocean water in large measure replaces the silt laden waters of the bank.

In other words, the coral patches which rim the Bahama Bank have merely grown in modern times near the seaward edges of a submerged flat, the extraordinarily level character of which can only be explained by assuming it to have been formed in conformity with sea level.   Only a water-level could be so flat.

Daly's (1915, *Proc. Amer. Acad. Arts and Sci.,* Vol. 51, pp. 157–251) opinion that the cooling of tropical seas in glacial epochs had much to do with determining the relative abundance of corals, has opened an interesting field for research, but according to Vaughan (1919, *U. S. National Museum Bulletin* No. 109, p. 256), the West Indian fossil reefs do not support this idea, for corals grew extensively in this region in Pleistocene times.

W. M. Davis, in numerous papers,[1] has called prominent attention to the following well-established facts: That under still-stand conditions, if the land be not surrounded by reefs, the sea will cut into the cliffs faster than the valleys can be excavated by subaërial erosion, and thus the streams will cascade into the sea.   Then if the island subsides, or the sea level rises, and drowns the valleys, the submarine slopes at the spur-ends will be steeper than the slopes of the submerged sides of the drowned valleys.   Also silt will be largely pocketed at the stream mouths in the inner ends of the drowned valleys, and will settle to the bottom before it reaches the

[1] A good résumé is given in Davis, 1919, *Trans. New Zealand Inst.,* Vol. 51, pp. 6–30.

shores along which corals are growing. I find, for example, that the coarse brown bottom mud of the mid-channel line of Pago Pago Harbor near the inner end of the harbor between Blacklock's Wharf and Pago Pago Stream consists, by weight, of 67 per cent. of volcanic material insoluble in hydrochloric acid and 33 per cent. of calcareous elements composed of shells, *Halimeda*, etc. At mooring buoy " B " about one third the distance from the inner end to the mouth of the harbor the bottom mud is finely divided, brown in color, and 51 per cent. volcanic. At mooring buoy " C," however, which is only 300 meters outward beyond buoy " B," the bottom mud is brown-gray in color and contains only 18.5 per cent. of volcanic elements. While at the mouth of the harbor the mud is a finely divided light gray deposit and contains only 6 per cent. of volcanic material. Thus the bulk of the volcanic silt is deposited on the harbor bottom before it goes more than one-third the distance from the inner end of the harbor to the mouth.

Thus, as Davis shows, coral reefs could form more readily around an emerged or a still-stand shore-line. Davis is the most active defender of Darwin's coral reef theory, yet the sequence of fringing reefs being converted into barrier reefs through subsidence of the land or by rise of sea level, and finally the conversion of these barrier reefs into atoll rims has not been proven even in a single instance, although it is the crux of Darwin's theory. As Davis admits we have not been able to read the history of the atolls, for there is no central island whose shore line can be interpreted.

There is on the contrary evidence that barrier reefs have in many places arisen as barriers along the seaward edges of submerged plateaus and remained such throughout their history, or have fused in places with fringing reefs which grew contemporaneously outward from the shores. Thus we have Vaughan's evidence that the old elevated reef of Florida which now constitutes the islands from Soldier's Key to the southern end of Big Pine Key is not a mere elevated part of the limestone platform upon which it grew for the platform is of oölitic formation and contains very few corals.

As has been pointed out by Daly, Darwin's theory does not explain the nearly uniform depth of about 20 fathoms, and the re-

markably flat floors, of the bottoms of Pacific lagoons; whereas such facts are readily understood if we suppose the ocean level to have risen about 20 fathoms since glacial times.   An obstacle to the general acceptance of Daly's theory lies, however, in the fact that if these level-bottomed submerged banks were formed at a time of lowered ocean level caused by the withdrawal of water from the seas to form the polar ice-caps, then the submarine banks of the tropical Pacific should be submerged to the same depth as those of the tropical Atlantic, but over the Bahama Banks we find an area of 27,000 square miles with depths only varying from 2 to 5 fathoms, instead of 15 to 20 fathoms as in the Pacific atoll lagoons.

On the other hand, the remarkably uniform and relatively narrow width of considerably less than a mile shown by the atoll rims of the Paumotos, Ellis, Gilbert, and Marshall Islands suggests that these atoll groups are all of about one and the same age, and as we now know the growth-rate of Pacific corals to be almost twice as rapid as that of corresponding genera in the Atlantic it would seem that these atolls could have attained their present stage by growth commenced after the close of the last glacial epoch.   The living coral reefs of the Pacific are probably less than 40,000 years old, and this is strongly suggestive of the validity of Daly's theory in so far as it applies to the modern reefs of the Pacific.   The growth-rate of Samoan corals is rapid, massive *Porites* heads growing upward about 18 mm., branched *Porites* 30 mm., *Pocillopora* 38 mm., and *Acropora* 55 mm., per annum.   Thus a reef of massive *Porites* might grow upward 100 feet in 1,600 years.   It will be recalled that Stanley Gardiner estimated that in the Maldives a coral reef might become 100 feet thick in 1,150 years; and thus our independent estimates are of the same order of magnitude.

Making use of diving apparatus, I have studied the reefs at depths of 2 to 6 fathoms, and find that when corals die which grew in depths below the influence of the breakers, they commonly remain in place and soon became coated with layers of lithothamnion, and are thus not only preserved as elements of the reef but the stony mass actually increases in volume, the lithothamnion cementing all dead elements of the reef into a more or less compact framework into the interstices of which sand and other fragments soon settle.

It seems probable that the reefs now living in the Pacific are structures which have originated in modern times upon submerged slopes and platforms of marine erosion. Being not more than 40,000 years old, these reefs have not existed long enough to have been subjected, except in rare instances, to appreciable subsidence or elevation of the land masses upon which they have attained a foothold.

GUYOT HALL,
    PRINCETON UNIVERSITY.

GOLGOTHA.

By PAUL HAUPT.

(Read April 24, 1920.)

The Church of the Holy Sepulcher in Jerusalem, northwest of the Dome of the Rock on the site of the Solomonic Temple, is supposed to be built over the tomb in which the body of Christ was laid by Joseph of Arimathea (OC 34, 184).[1] This locality would seem to have been within the walls of Jerusalem at the time of the Crucifixion (RB 541[b]; DB 2, 589[b]. 595[a]; contrast RE[3] 7, 49, 28; EB 2430, 32, ii). But the place of execution was outside the city, in a conspicuous spot, beside a frequented road leading to one of the gates, near a garden with a new rock-cut tomb (Mark 15, 29. 40; Heb. 13, 12; Matt. 27, 39; 28, 11; Luke 23, 49; John 19, 20. 41).

The original Church of the Holy Sepulcher was built by Constantine the Great (323–337) who is said to have commissioned Bishop Macarius of Jerusalem to search for the tomb and the cross. The bishop reported that the Holy Sepulcher was under the temple of Aphrodite which, according to later writers, had been built by Hadrian in 135. Macarius may have been influenced by the desire to obtain two magnificent Christian churches instead of the pagan sanctuary of Venus (RB 541[a]). Similarly the traditional scene of the Nativity is alleged to have been desecrated during the reign of

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[1] AJSL = *American Journal of Semitic Languages.*—AS = Anglo-Saxon. —AV = Authorized Version.—BL = Haupt, *Biblische Liebeslieder* (1907).— DB = Hastings, *Dictionary of the Bible.*—EB = Cheyne-Black, *Encyclopœdia Biblica.*—EB[11] = *Encyclopœdia Britannica,* eleventh edition.—JAOS = *Journal of the American Oriental Society.*—JBL = *Journal of Biblical Literature.*— JHUC = *Johns Hopkins University Circulars.*—JSOR = *Journal of the Society of Oriental Research.*—OC = *The Open Court.*—OHG = Old High German.—*Pur.* = Haupt, *Purim* (1906).—RB = Riehm-Bæthgen, *Handwörterbuch des Biblischen Altertums.*—RE[3] = Hauck, *Realencyclopädie für Protestantische Theologie und Kirche,* third edition.—ZAT = *Zeitschrift für die alttestamentliche Wissenschaft.*

Hadrian (117–138) by a temple of Adonis; but the inn at Bethlehem, where Jesus is said to have been born, must have been near the road from Jerusalem to Hebron, northwest of Bethlehem, not in the southeastern corner of the village (*Monist*, 30, 158, n. 35).

A rock-cut tomb under the Hadrianic temple of Venus was assumed to be the tomb of Christ. In another cavity of the rock, 280 feet to the east, three crosses were found, which were supposed to be the crosses on which Christ and the two thieves were crucified. One of the crosses had miraculous power: a crippled old woman stretched on it was cured. Constantine built a magnificent church over the place where the crosses had been discovered, and a smaller church over the reputed Holy Sepulcher. A hill between the two churches was supposed to be Mount Golgotha. The Basilica of the Holy Cross is no longer extant. The Church of the Holy Sepulcher was destroyed repeatedly; the present building was erected in 1810.

The discovery of the Holy Sepulcher and the two churches built by Constantine are described by the Father of Church History, Eusebius of Cæsarea (*c.* 260--*c.* 340) in his Life of Constantine; but this biography is untrustworthy. Later writers attribute the discovery of the Holy Cross to Constantine's mother, St. Helena, who was, according to St. Ambrose, an inn-keeper (*stabularia;* RE[3] 7, 616, 26). Constantine the Great was the illegitimate son (EB[11] 16, 988[a]; RE[3] 10, 759, 21) of St. Helena and Constantius Chlorus, the co-regent of Diocletian. In 289 Constantius married Maximian's step-daughter. In his Life of Constantine, Eusebius also relates that the emperor saw in the sky at noonday a flaming cross with the legend 'Εν τούτῳ νίκα (*In hoc signo vinces*) whereas other contemporaries state that this sign was seen in a dream. Under Constantine the cross, which is an ancient pre-Christian symbol, became the emblem of Christianity.

St. Helena's discovery of the Holy Cross, which is first mentioned by Rufinus who died in 410, is commemorated on May 3. Since 1895 the name of this festival in the *Diario Romano* is no longer Invention (*Invenzione*) of the Holy Cross, but Rediscovery (*Ritrovamento*) of the Holy Cross, because according to an older legend the true cross was found under Tiberius who died in 37 A.D.

(EB[11] 7, 506[b]). St. Helena is said to have found, not only the true cross, but also the superscription over the head of Jesus on the cross as well as the nails with which He had been crucified. Constantine is supposed to have sent a piece of the Holy Cross to Rome where it is still exhibited in the church of S. Croce in Gerusalemme on May 3 as well as on Good Friday and the third Sunday in Lent. In a vault of this church the superscription on the cross is said to have been accidentally found in 1492. If Constantine had sent it to Rome, it must have been lost sight of for more than a thousand years. Two of the nails, with which Christ was affixed to the cross, are reputed to be preserved at Milan and Trier, respectively (EB[11] 7, 507[a]). St. Helena is supposed to have presented to Trier also the seamless robe (*tunica inconsutilis*) of Christ. It was exhibited in 1891 to two million pilgrims. There are twenty holy seamless coats, *e.g.*, at Argenteuil near Paris, St. John Lateran at Rome, etc. (RE[3] 17, 60, 45).

The authenticity of the site of the Holy Sepulcher has been questioned from early times. The Father of Biblical Geography, Edward Robinson, stated (1841) after his researches in Palestine that the traditional site could not be the true one. A German bookseller, Jonas Korte, of Altona, who visited Jerusalem in 1738, suggested that Golgotha was west of Jerusalem, near the Mâmilla Pool (JAOS 39, 143, b) which is ½ mile northwest of the Jaffa Gate. In 1842 Otto Thenius, of Dresden, came to the conclusion that the place of crucifixion was above Jeremiah's Grotto outside the Damascus Gate in the north, and this view of the German Biblical critic has been endorsed by Canon Tristram, Dr. Selah Merrill, General Gordon, Col. Conder, etc. (EB[11] 24, 657[b]). Three years before his death at Khartum in 1885 Gen. Gordon spent a year in Palestine, studying Biblical history and the antiquities of Jerusalem. An ancient rock-cut tomb, about 200 yards west of Jeremiah's Grotto is sometimes called Gordon's Tomb of Christ. This tomb, however, seems to be later than the time of the Crucifixion. In 1847 the author of *The History of Architecture*, James Ferguson, made the startling proposal that the Dome of the Rock on the site of the Solomonic Temple was the church built by Constantine over the

Holy Sepulcher. But the Dome of the Rock, also misnamed the Mosque of Omar, was erected by Abd-al-Malik in 691, and the mosaic map discovered at Medeba in 1896 shows the Church of the Holy Sepulcher in its present location. This map formed the floor of a basilica built in the fifth or sixth centuries.

I believe that the Crucifixion took place at the Topheth in the Valley of Hinnom, south of the Harsith Gate in the southeastern corner of Jerusalem. This gate was also called Ashpoth Gate which is generally mistranslated Dung Gate; but Ashpoth is the Hebrew form of Topheth, *i.e.,* Aram. *těfâth* with the vowels of *bósheth,* shame, because the Jews did not pronounce the objectionable word Topheth, but substituted for it *bósheth,* shame (JBL 37, 233). In the same way the names of Astarte and Melech, the god of the Ammonites, appear in the Hebrew Bible as Ashtoreth and Molech, respectively. Also the name of the valley (now filled up with rubbish) between the eastern and western hills, which led to the Topheth in the Valley of Hinnom, was Topheth valley. The name *Tyropœon* (EB[11] 15, 332) valley, given by Josephus, is due to a misunderstanding of the original Hebrew name *gê-hash-shěphôth,* in which *shěphôth* (cf. Neh. 3, 13) is the Hebrew form of the Aramaic *těphâth,* Topheth, but it was misinterpreted as *cheeses* (Tyropœon, τῶν τυροποιῶν means *of the cheesemakers*) on the basis of 2 Sam. 17, 29 (EB 3091. 2423, n. 4). According to Wetzstein (ZAT 3, 276) *shěphôth* in 2 Sam. 17, 29 denotes *thick cream* of cow's milk (not ewe's milk) in small wooden cylinders (see cut in RB 1742). In Damascus, cream is called *shifâ-'l ḥalîbı,* top of the milk (*cf.* Austrian *Obers*). The word in 2 Sam. 17, 29 should be spelled with *Sîn* (not *Shîn*).

Topheth (more correctly *Těphâth,* Heb. *Shěphôth* or *Ashpôth*) means *fire-place,* cremator, incinerator. Refuse and rubbish were deposited there, especially potsherds. Harsith (*i.e.,* potsherd-dump) corresponds to the Roman *Monte Testaccio* (Lat. *Mons Testaceus*) on the left bank of the Tiber in the southwestern corner of Rome. This accumulation of potsherds is about 2,500 feet in circumference, and about 115 feet high. The *Mons Testaceus* of Jerusalem was also called Potter's Field, and afterwards Field of Blood, because

it was used as a place of public execution in the Roman period, *cf.* the blood-ban of the Fehmic courts on the Red Earth of West-phalia (EB[11] 10, 237[a]). The two explanations of the name Field of Blood (Aram. *ḥăqăl-dĕmâ;* AV *Aceldama;* RV *Akeldama*) given in Matt. 27, 8 and Acts 1, 19 represent later legends. Matt. 27, 10 is based on a misinterpretation of a line of the Maccabean poem in Zech. 11, 13 (misattributed to Jeremiah) where we must read *el-hay-yaçár*, into the treasury (Peshita: *bêth-gázzâ*) instead of *el-hay-yôçér*, to the potter. Heb. *yaçár,* treasury, is a byform of *ôçár,* from *waçar = naçar,* just as we have in Aramaic: *yĕgár* and *ôgár,* heap of stones. The traditional site of Aceldama (see cut RB 232) is on a level overhanging the Valley of Hinnom on the northeastern slope of the Hill of Evil Counsel, where Caiaphas is said to have taken counsel with the chief priests and elders of the people against Jesus to put Him to death (Matt. 26, 3; 27, 1; John 11, 49). The soil of this place is supposed to quickly consume dead bodies; 270 shiploads are said to have been taken to form the *Cimetero dei Tedeschi,* south of St. Peter's, in Rome, and 53 to the Campo Santo in Pisa (DB 1, 59[b]).

The Targum uses *qilqíltâ* (= Syr. *qîqáltâ*) for Heb. *ashpôth* (1 Sam. 2, 18; Ps. 113, 7) or *ḥarsîth* (Jer. 19, 2). This is the original form of the name Golgotha which represents a simplified pronunciation of *golgóltâ,* just as we say *fugleman* for *flugleman* = German *Flügelmann.* In Syriac we find *Gâgóltâ* instead of *Gol-gotha.* This name is interpreted as The Skull (Aram. *gulgúltâ,* Heb. *gulgólth,* Arab. *gálgalatun,* now pronounced *jáljalah*). According to a pre-Christian legend, which we find *e.g.,* in the Ethiopic Synaxaria, Noah sent his son Shem (accompanied by Melchizedek; *cf.* JOSR 2, 79) to bury the body of Adam in the center of the earth which is Calvary (Ethiop. *Qarânyô;* Dillm. *Chrest.* 16). Lat. *calvaria* means *skull,* brain-pan. During the Crucifixion the blood of Christ trickled down on the body of Adam and restored him to life (DB 2, 226[a]). The skull and the bones at the base of a crucifix represent the skull and the bones of Adam (RE[3] 7, 52, 25). St. Augustine says, The physician was raised over the patient (RB 540, * *). Some think that the name Golgotha was derived from the

round and skull-like contours of the place. The eminence above the Grotto of Jeremiah, not far from the Damascus Gate in the north, has a strong resemblance to a skull. Others believed that the site of the Crucifixion received this name because it was full of skulls. The Jews did not crucify persons alive, and even when they gibbeted criminals after their execution, they interred them by nightfall, so that there could be no accumulation of skulls and dead bones; but the Romans allowed the bodies of crucified malefactors to decay on the cross. Horace (*Ep.* 1, 16, 48) says: *Non pasces in cruce corvos;* cf. Byron's *ravenstone* = German *Rabenstein* (*stein* = rock, eminence, hill). Golgotha may be the prototype of our *gallows* (AS *gealga*, OHG *galgo*, Goth. *galga*) which denotes originally the cross on which Christ was crucified, so that Mount Golgotha corresponds in some respects to our Gallows Hill (German *Galgenberg*). The cross was the Roman gallows. *Gallows* is generally identified with Lithuanian *žalga*, pole, Lat. *pertica*. The gallows at Montfaucon near Paris had pits beneath, into which the bodies fell after disarticulation by exposure to the weather (EB[11] 11, 422). After the massacre of St. Bartholomew on August 24, 1572, the beheaded body of Coligny was gibbeted for several days at Montfaucon (RE[3] 4, 227, 1). The bodies suspended on gibbets were often smeared with pitch to prevent too rapid decomposition.

After the fall of Jerusalem in 70 A.D. Titus is said to have crucified so many Jews that there was neither timber for the crosses nor place to set them up (DB 1, 528[b]). The upright stake of the cross was firmly planted in the ground and remained there as a permanent fixture (RE[3] 11, 91, 38). The condemned criminal carried only the crosspiece or transverse beam (Lat. *patibulum*) to the place of execution (RE[3] 11, 91, 31; DB 1, 528[b]). The upright stake was not more than nine feet high; the feet of the crucified malefactor were but slightly elevated above the ground (*Pur.* 6, 24; BL 102, *). The Romans may have called the accumulation of potsherds and other rubbish, which was used as a place of execution, *Mons Testaceus*, and this may afterwards have been interpreted to mean Mound of Skulls, because Lat. *testa* means both *potsherd* and *skull*, so that *Golgotha* (= Aram. *gulgúltâ*) instead of the original *qilqítâ* would represent a popular etymology which was

favored by the fact that the Semitic *q* is often pronounced as *g;* even *k* may become *g* under the influence of an *l, r,* or *n:* Assyr. *Tukulti-pal-esharra* appear in the Old Testament as *Tiglath-pileser* (JBL 36, 141, n. 3) and *Sharru-kênu* as *Sargon;* the Hebrew name of the Sea of Galilee, *Chinnereth* (Josh. 13, 27; OC 23, 199) became *Gennereth,* and with transposition and *s* instead of *th: Genneser* or, with *a* instead of *e* owing to the final *r, Gennesar* (1 Mac. 11, 67).

The correct translation of the Hebrew name *Sha'r Ashpoth* is not Dung Gate, but *Topheth Gate* (JBL 37, 233). The other name of this gate, Harsith Gate (Jer. 19, 2) is mistranslated in AV: East Gate, and in the margin: Sun Gate; RV retains the Hebrew word: the gate Harsith, but adds in the margin: *the gate of potsherds.* In certain parts of England *shard* is used not only for *potsherd,* but also for *dung,* ordure. St. Jerome describes Topheth as a pleasant spot in the Valley of Hinnom with trees and gardens watered from Siloam, *i.e.,* in the gardens below Siloam at the junction of the Valleys of Hinnom and Kidron (DB 2, 386^a. 387^a; 4, 798^b, below).

Both Hinnom and Kidron mean *resting-place:* Heb. *hinnôm* is the infinitive of the reflexive-passive stem of *nûm,* to slumber, and *qidrôn* is a transposition of *riqdôn,* from *raqad* which means in Arabic *to sleep.* Arab. *ráqdah* denotes the time between death and resurrection; *márqad* signifies *resting-place,* grave. The Valley of Hinnom and the Kidron ravine seem to have been ancient burial-grounds. The Greek Bible has for the Valley of Hinnom the term *polyándrion,* a burial place for many, and according to Jer. 31, 40, not only dead bodies were deposited there, but also offal (JBL 38, 45). Heb. *gê-hinnôm,* the valley of Hinnom, is the prototype of Gehenna. According to 2 Kings 23, 6 the graves of the children of the people (*i.e.,* the common people) were in the Kidron valley. In the pre-Exilic period heathen images and altars were repeatedly cast into the Kidron valley and burned there. The flaming pyres with the dead bodies of the apostate Jews, on which the Maccabees feasted their eyes when they went to worship JHVH in the Temple, were in the Kidron valley between the Temple and Mount Olivet. There were plenty of corpses to feed the worms and the fires, so *their worm died not, and their fire was not quenched* (JHUC, No.

306, p. 13). The last two verses of the Book of Isaiah represent an appendix which was added about 153 B.C. (AJSL 19, 135). The Kidron valley is also called the Valley of Jehoshaphat (JAOS 34, 412). The Jews as well as the Christians and the Mohammedans of Palestine believe that the Last Judgment will be held in the Kidron valley, and it is the dearest wish of every Jew to find a grave there. The whole of the left bank of the Kidron opposite the Temple area is covered with the white tomb-stones of the Jews (EB 2662). Some Jewish teachers believe that the bodies of the righteous will roll back under the ground to Palestine to obtain a share in the resurrection preceding the Messiah's reign on earth (DB 2, 562ª). The two valleys have often been confounded: *e.g.,* the great Moslem traveler Ibn Batûtah (1204–1378) says that the valley of Gehenna was east of Jerusalem.

Golgotha is identical with Topheth in the Valley of Hinnom, south of the Harsith Gate in the southeastern corner of Jerusalem. It was a rubbish-heap like the Roman *Monte Testaccio,* formed of potsherds and other refuse.[2] It was therefore known also as Potter's Field, and afterwards it was called Field of Blood, because it was used by the Romans as a place of public execution. The original form of Golgotha was *qilqîltâ,* refuse. The form Golgotha, which is also the prototype of our *gallows,* represents a popular etymology. The Romans may have called the Harsith *Mons Testaceus,* and since *testa* means both *potsherd* and *skull,* this name may have been interpreted as Place of Skulls. After the Harsith had been used by the Romans as the place of crucifixion for a number of years, skulls may have been more in evidence there than potsherds. Jeremy Taylor, whose Life of Christ was published in 1649, calls the scene of the greatest event in Jerusalem's history *a hill of death and dead bones, impure and polluted* (EB 1753). The Mohammedans sometimes give the Church of the Holy Sepulcher the nickname *Kanîsat-al-Qumâmah,* Church of Rubbish (RB 540ª) instead of *Kanîsat-al-Qiyâmah,* Church of the Resurrection.

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[2] In Corfu the people at a given signal on Easter Eve throw vast quantities of crockery from their windows and roofs into the streets. This is interpreted as an imaginary stoning of Judas Iscariot. Descendants of the traitor were supposed to be among the Jews of Corfu (EB¹¹15, 536ª).

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104 SOUTH FIFTH STREET

1920

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Essays may be written in any language, but, if not in English, must be accompanied by an English translation.

No essay which has been already published or printed, or for which the author has received any prize or profit of any nature whatsoever, shall be accepted in competition for the prize.

Essays must be typewritten on only one side of the paper, and six copies must be furnished by their respective authors for the use of the Committee of Judges.

The literary property of such essays shall be in their author, subject to the right of the Society to publish the crowned essay in its " Transactions " or " Proceedings."

The Society reserves the right not to award the prize if none of the competing essays is deemed worthy of it.

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</div>

The essays must be sent, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A.

THE HIGH VOLTAGE CORONA IN AIR.

BY J. B. WHITEHEAD, PH.D.

(Read April 24, 1920.)

Atmospheric air is an extremely good electric insulator. It has low specific inductive capacity, very low conductivity, and a relatively high electric strength, or ability to withstand breakdown or spark-over between high voltage terminals. The name "corona" has been given to the continuous partial breakdown of air subjected to electric strain, and it always appears as a glow or brush discharge confined to one or both high voltage terminals with a region of unbroken air in between.

When voltage is applied to a pair of parallel plates in air and slowly raised, the air withstands the strain up to a definite value of voltage and then breaks down completely with a heavy sparkover or arc between the plates. (See Fig. 1.) In this case the electric field intensity or the number of volts per centimeter is uniform throughout the region between the plates, being equal to the voltage applied divided by the distance between them. The electric intensity at which breakdown occurs in the air at normal atmospheric pressure is about 32 kilovolts per centimeter. If needle points are used, or a hollow cylinder and a wire on its axis, instead of the parallel plates, a quite different behavior of the air appears. On raising the voltage the air breaks down in the form of a brush or glow discharge immediately around the needle points and at the surface of the central wire, but the breakdown is limited to a small distance and there is no sparkover or complete rupture until a much higher value of voltage is reached.

The interest in the cases of the points and the central rod and cylinder lies in the fact that the electric field or voltage gradient is not uniform over the distance between terminals, being highest at

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the surface of the conductor and more so the smaller its radius of curvature, and also in that the value of electric intensity at which corona first appears may be much higher than 32 kilovolts per centimeter. In fact in these cases values of electric intensity higher than 32 kilovolts per centimeter are reached with no resulting evidence of breakdown or brush discharge.

Evidently we are here in the presence of a striking property of

$$E_s = \frac{V}{\ell}$$

$$E_s = ?$$

$$V = volts.$$
$$E_s = surface \ intensity.$$

$$E_s = \frac{V}{r \, log \frac{R}{r}}$$

$$E_s = ?$$
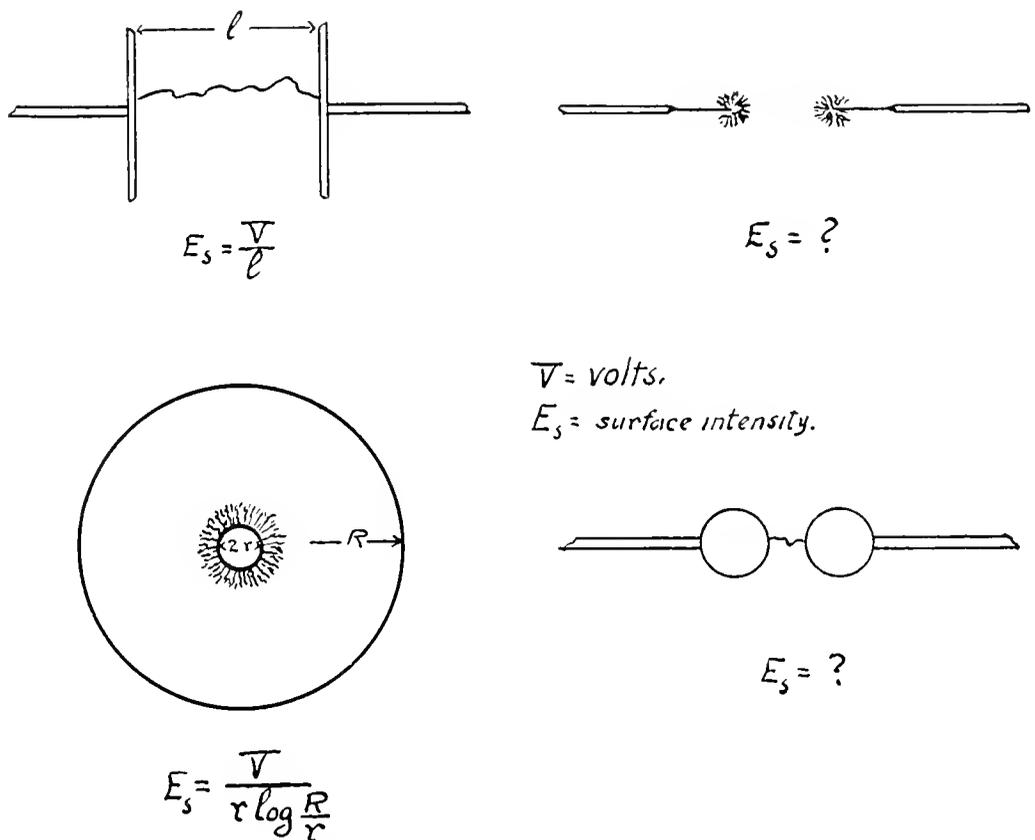
Fig. 1.   Spark and Corona.

the air showing a definite influence of the volume of air subjected to electric strain on the intensity at which initial breakdown takes place. It would appear that here is a splendid opportunity for further study of the molecular and atomic structure of the air. The phenomena are extremely definite and constant in the case of the central wire and cylinder, and all of the conditions are susceptible of accurate measurement. However the physicist appears not to be interested in the electric properties of air at pressures in the neighborhood of that of the atmosphere. Professor J. T. Town-

send has proposed an interesting explanation of the fundamental law of corona formation in terms of the theory of ionization by collision, but this theory is based entirely on experiments at very low pressures, quite outside the range in which the first definitely marked corona phenomena lie. So far as the writer is aware, Townsend's is the only attempt to coördinate corona phenomena with modern physical theory.

In two particular aspects the corona presents difficulties for the electrcial engineer: first, the presence of corona is always accompanied by a loss or waste of energy; and second, in the presence of corona insulation deteriorates rapidly and the insulating properties of the neighboring air are lowered. In either case the probability of sparkover and shortcircuit is greatly increased.

The energy loss attendant upon corona introduces important limitations in the design of long distance electric transmission lines. The voltage of such lines is made high in order to reduce the magnitude of the current to be carried, and therefore the size of the conductors, the cost of the conductors being a principal item in the total cost of the transmission line. The tendency therefore is to higher and higher values of voltage. As the voltage is increased, however, the corona forming point is reached, and in order to prevent the presence of corona the distance between the transmission wires must be increased.

It is especially important to keep the voltage well below the corona forming value, for above it the loss increases very rapidly. According to F. W. Peek, from measurements made on a section of a modern transmission line, the power loss may be expressed

$$w = kf(e - e_0)^2 \qquad\qquad (1)$$

where w is in watts, f is the frequency, e is the maximum value of the voltage and e_0 the voltage at which corona first begins; that is to say, the loss increases with the square of the excess of voltage above the corona forming value. (See Fig. 2.)

The above formula applies to alternating voltage. No complete study has been made of the loss at continuous voltage, probably because little use is made of high continuous voltage in the field of

electrical engineering. It has not yet been determined definitely that the law as proposed by Peek is the correct one. The results of R. D. Mershon, one of the earliest observers and workers in this field, on an experimental line at Niagara Falls, are distinctly at variance with the results of Peek, as are those of Jakobsen on an operating transmission line in Peru. On the other hand, the observations of Faccioli in Colorado, and Harding on an experimental
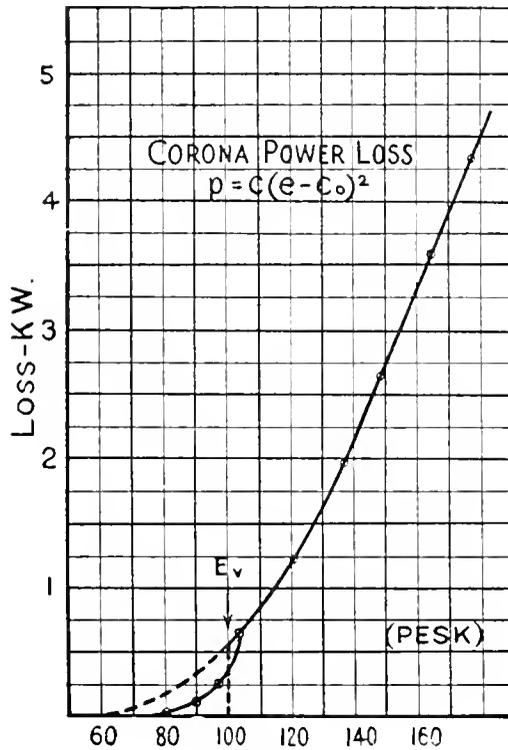
Fig. 2.

line at Purdue University, give results in good agreement with Peek's formula. The difficulty appears to be that the formula does not give correct values for voltages only slightly in excess of the initial corona forming value, the explanation being that surface irregularities and atmospheric deposits of various descriptions on the surface of the wire result in partial corona formation at values below those which would obtain for a perfectly round clean wire. As the voltage is pushed above the corona forming value, these initial losses become relatively small and the rising curve showing the relation between loss and voltage gradually merges into the true curve for a smooth wire. The law as announced by Peek is based on the upper region of this curve. (See Fig. 2.)

No explanation has been offered for the foregoing law, nor does an obvious explanatioin suggest itself. It is not difficult, however, to see that the loss should increase sharply above the critical voltage. Corona first begins when the maximum of the alternating voltage reaches a definite value, which, in the case of a smooth round wire, is very sharply marked. Above this value corona starts on each half wave at this same definite value, whatever the maximum value of the voltage wave may be, and on the descending half wave corona ceases at about the same value or very little below it. Corona is thus periodic and with increasing voltage occupies a larger and larger area at the top of successive half waves of alternating voltage. (See Fig. 3.) In the neighborhood of the critical
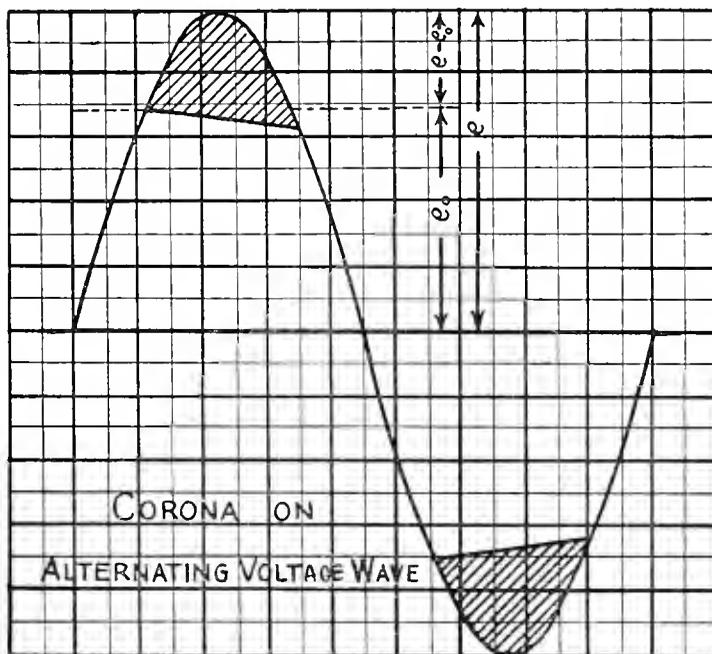
FIG. 3.

corona forming value, when corona is limited to a short interval at the crest of the wave, the loss will evidently be proportional to the frequency since the number of breakdowns per second increase with the frequency. However, with increasing voltage the aggregate time during which the corona actually exists becomes more and more nearly equal for all frequencies. As to the influence of voltage, with increasing voltage the volume of corona increases, and since this means increased ionization and conductivity of the

air, the current also increases. The power loss being the product of voltage and the current increasing with the excess of voltage above a certain critical value, we should therefore expect the loss to increase as some power of the voltage higher than the first but that it should be as the second power of the excess voltage in not evident.

Further studies of the nature of the power loss and of the exact law governing it are greatly needed. It seems probable that the observations which have already been made on transmission lines are about as satisfactory as can be obtained in this way. Since it is important to adopt a voltage well below that at which corona forms, and since the values at which corona will start on clean wires are now accurately known, it does not appear likely that transmission engineers will go very far in further investigation. There is here, however, again an admirable opportunity for laboratory study.

It will be seen therefore that it is important to know accurately the laws connecting the physical constants of an electric circuit and the voltage at which corona begins. A number of experimental studies of this question have been made and some of the earlier of these were reported to this society by the present writer several years ago. Since then the law of corona formation has been well established and it is the purpose of this paper to give the results of some of the more accurate measurements. These measurements have been made with the assistance of an instrument in which the otherwise troublesome corona pheonmena have been turned to useful account as a means for the accurate measurement of high alternating voltage. The accurate measurements referred to were made on this instrument, which is called the "corona voltmeter."

The Corona Voltmeter.—The corona voltmeter makes use of the fact that corona forms on a clean round wire in air at a sharply marked definite value of voltage, dependent in a simple relation on the density of the air. The range of the instrument is extended to wide limits by enclosing the wire and cylinder and varying the density of the air.

The essential elements of the instrument are a central rod, or wire, on which corona forms, another concentric cylinder forming

the opposite terminal, an outer air-tight containing case in which the air pressure may be varied, and convenient means for determining accurately the first appearance of corona. All of these features are indicated in diagrammatical form in Fig. 4.

In Fig. 4 A is the central wire, or rod. B is the concentric
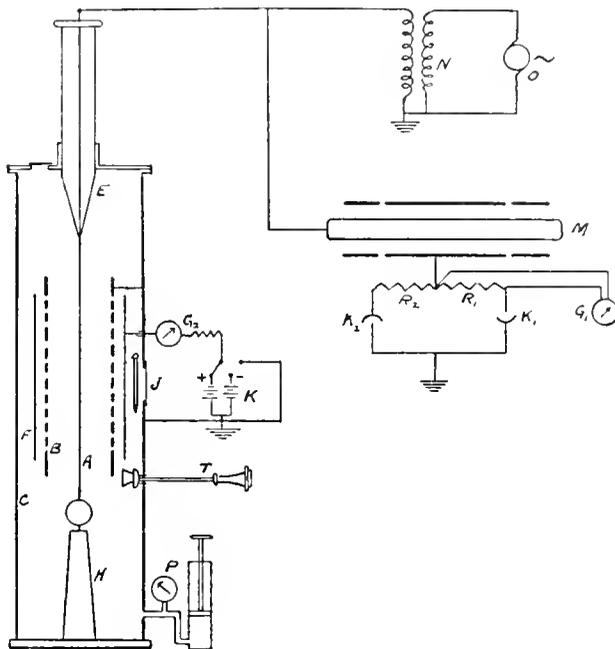
FIG. 4.

cylinder forming the opposite terminal which is connected to ground; C is the outer air-tight containing case with air pressure control at the pump P; and E is a high voltage insulating bushing for connecting the source of high potential N to the corona rod A; H is a porcelain insulator maintaining the lower end of A in fixed position.

Two simple methods have been developed for detecting the initial appearance of corona as the voltage on A is slowly raised. The first of these makes use of the fact that the presence of corona sets up a copious state of ionization. The cylinder B is therefore perforated, and just outside cylinder B a continuous surrounding cylinder F is placed, carefully insulated from B. Connection is made to this outer cylinder through the galvanometer G_2 either directly to ground or with a continuous electromotive force in series. At the first beginnings of corona the air between cylinders B and F

is ionized and therefore becomes conducting, resulting in a sharp deflection of the galvanometer G_2. Fig. 5 is a series of curves showing how sharply the galvanometer deflection occurs as related to corona voltage.

The corona has an audible sound even in the open. When the corona wire is enclosed, as in the corona voltmeter, this sound is gathered and intensified. At atmospheric pressure the ear placed at a small opening in the case C will detect the very first appearance of corona, which will be very sharply marked. In order that the sound may be utilized, when the pressure is of value other than that of the atmosphere, a telephone transmitter is included inside
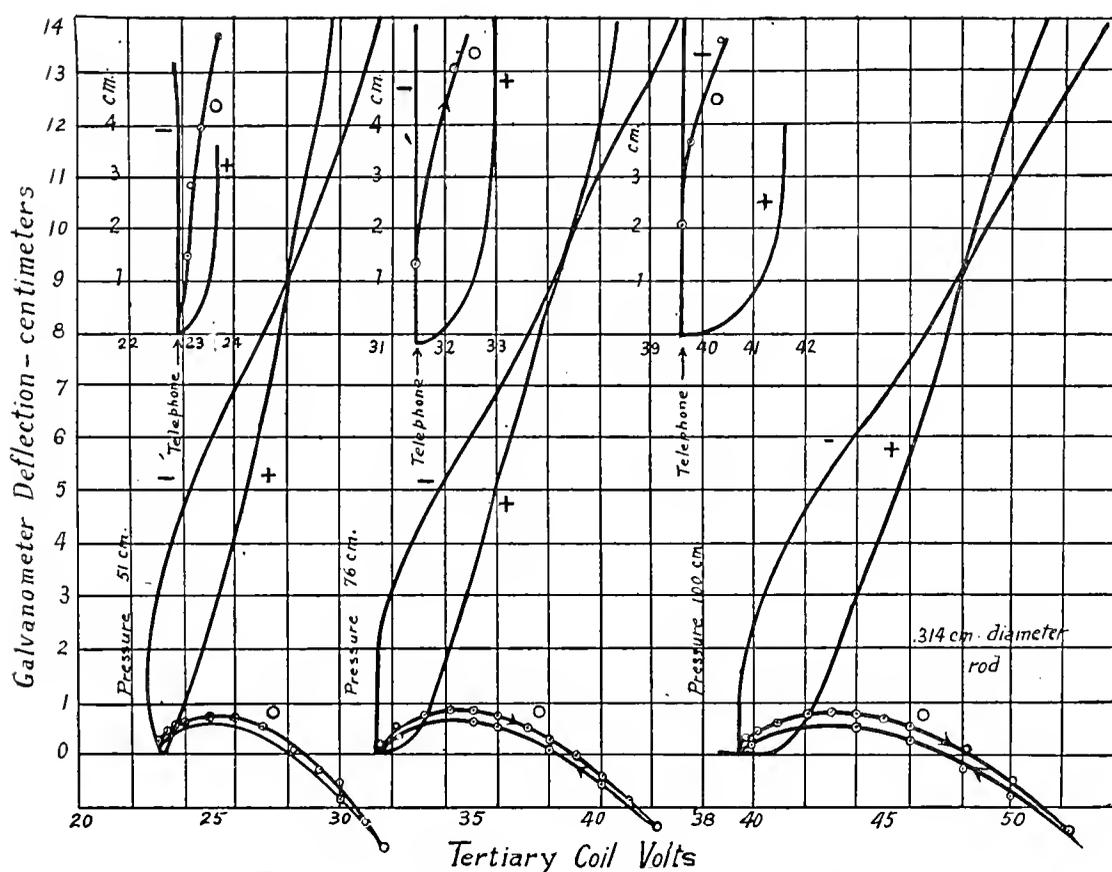
Fig. 5 Galvanometer as Detector of Corona

the casing connected with the receiver outside, as shown at T, Fig. 4. The telephone gives a clear note on the first appearance of corona and the indications of telephone and galvanometer are exactly contemporaneous, as indicated in Fig. 5.

In order to calibrate the instrument and thus determine ac-

curately the law of corona formation, it is necessary to be able to measure accurately the value of voltage applied to its terminals and to determine accurately the first appearance of corona. The instrument, as indicated in Fig. 4, is in fact the result of a long series of experimental studies of corona formation and the gradual development of methods of controlling and determining all the factors which enter. It has been known from the beginning of these studies that corona forming voltage gradient depends on the diameter of the wire and on the density of the air, no other factors entering. Moisture content of the air, for example, has no influence on corona forming intensity. A possible exception is the frequency of the alternating voltage which appears to have a very small influence, too small, however, to be of importance within the commercial range of frequency. The instrument therefore provides means for observing the pressure and temperature at P and J, and also means not indicated in Fig. 4 for removing the central rod A so that another of different diameter may be substituted.

The method of measuring the applied voltage is also indicated in Fig. 4. It consists of connecting an air condenser M, of known capacity, in parallel with the conora voltmeter and of measuring the charging current of this capacity. This charging current is a direct measure of the maximum value of the alternating voltage in terms of the capacity of the condenser and the frequency of the generator O.

The alternating charging current is connected to earth by the divided circuit $R_1 K_1$ and $R_2 K_2$. R_1 and R_2 are noninductive resistances and K_1 and K_2 are rectifying Fleming valves passing the positive and negative half waves respectively. R_1 therefore carries a pulsating unidirectional current, the average value of which may be measured on the calibrated d'Arsonval galvanometer G_1. The impedence of the $R_1 K_1 — R_2 K_2$ circuit is negligible compared with that of the condenser M. In order to withstand the high voltages used, and that it might have no loss, an air condenser was used at M. The condenser was of cylindrical type with flaring guardrings, as shown in the photograph, Fig. 6. The cylinders were made from cast iron water pipes, the diameters of the inner and outer

members being 29.5 cms. and 49.3 cms., respectively, and the length
of the central section of the outside member 76.2 cm. The capacity
of the condenser as measured was 8.28×10^{-15} microfarads.

In making observations the voltage of the generator O was
slowly raised and at the instant corona appeared, as indicated by the
galvanometer G_2 and telephone T, the galvanometer G_1 reading the
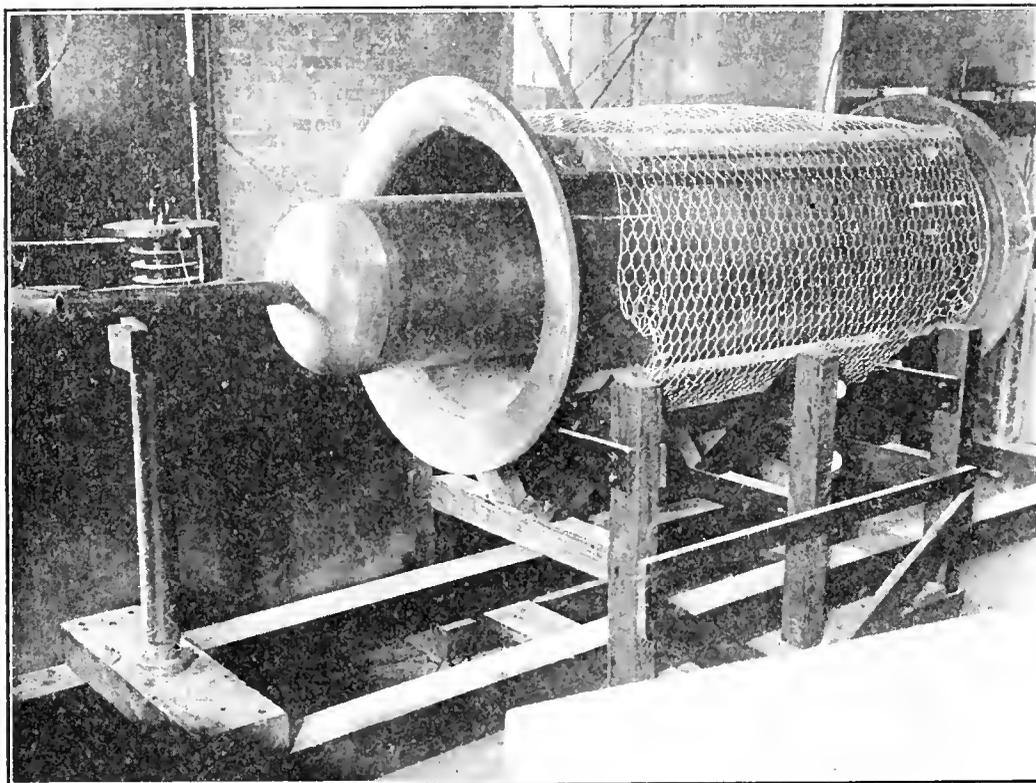
FIG. 6. Air Condenser.

condenser charging current was read, and at the same time the
temperature and pressure at J and P. The frequency was also
accurately measured by comparison with a standard tuning fork.
The reading of the calibrated galvanometer G_1 gives the charging
current of the air condenser M which, with the frequency, leads to
the maximum value of the alternating electromotive force corre-
sponding to corona formation. It only remains therefore to connect
this critical value of voltage with the conditions as to temperature
and pressure to arrive at the law of corona formation.

The form of the relation between voltage, temperature and
pressure and the diameter of the corona forming wire, as agreed

upon by several observers in recent years, is usually stated in the form

$$E = A\delta\left(1 + \frac{B}{\sqrt{\delta r}}\right),\qquad(2)$$

in which E is the critical or corona forming voltage gradient at the surface of the wire expressed in kilovolts per centimeter, r is the radius of the wire in centimeters, and δ the relative density of the air, having the value

$$\delta = \frac{3.92p}{263 + t},\qquad(3)$$

p being the pressure is centimeters of mercury, and t the temperature in degrees Centigrade.

A more convenient form of the relation for our purpose is

$$\frac{E}{\delta} = A + \frac{B'}{\sqrt{\delta r}},\qquad(4)$$

which gives a linear relation of $E\delta$ and $1/\sqrt{\delta r}$.

The above relatively simple relations have now been corroborated by a number of observers with fairly close agreement as to the value of A and B. The form of the law is the same for both continuous voltages and crest values of alternating voltages. With continuous voltage, however, there are appreciable differences in the values of the constants A and B as between positive and negative corona forming wire, the form of the law in each case remaining the same.

No attempt will be made in this place to give a complete review of the large number of observations which have been taken on ten different sizes of corona forming rod under wide variations of relative density δ. Table I, however, gives several sets of readings and indicates, particularly in columns 7 and 8, the accuracy with which the observations repeat themselves. Column 9 gives the readings of galvanometer G_1 measuring the condenser charging current, and column 14 is the reading of an ordinary alternating voltmeter connected to the low voltage terminals of the high voltage transformer. The readings of this voltmeter were not used in the calculations, but its indications provided at all times a convenient means for de-

termining the constancy of circuit and other experimental conditions. The observations were all collected in groups corresponding
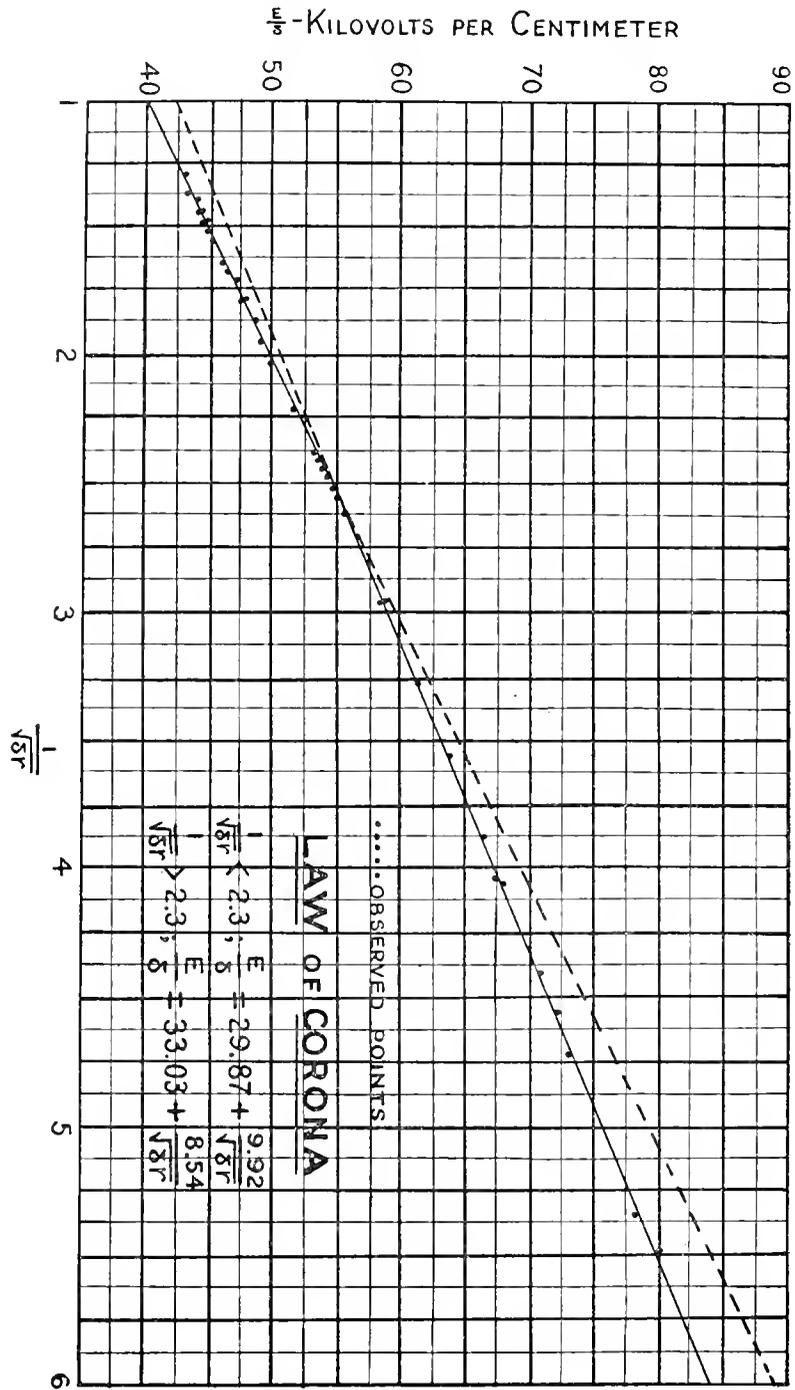
FIG. 7.

to approximately the same values of δ for each particular size of corona rod, and the values of E/δ and $1/\sqrt{\delta r}$ were calculated in each case. Obviously E, the value of the surface electric intensity

on the corona forming rod, is obtained from the measured value of the voltage and the dimensions of corona rod and outer cylinder B (Fig. 4). As these results were obtained they were plotted, and Fig. 7 shows the resulting relative location of the points. The equations of the straight lines were obtained by a method of analysis proposed by Steinmetz for deriving from a series of experimental values the most probable equation.

It will be seen that there is a linear relation between E/δ and $1/\sqrt{\delta r}$, but that there are two such relations resulting in two

TABLE I.

CORONA VOLTAGE READING.

.4765 Cm. Diam, Rod.

Freq.	Bar Press.	Temp.	Press Left.	Gauge Right.	Corr. Abs. Press.	Galvanometer							Terr. Coil Vol.
						Corona Reading.			Calibration.				
						Left.	Right.	Mean.	Left.	Right.	Volts 499 Ohms.	Milamp per Div.	
60.03	75.56	18.9	72.30	8.60		10.22	10.30	10.26	10.26	10.29	.3890		65.9
						10.23	10.30	10.26					65.95
					139.74							.07590	65.95
		19	72.00	8.90		10.22	10.30	10.26					65.95
						10.22	10.30	10.26	10.23	10.30	.3891		65.95
60.04	76.12	19.8				6.22	6.23	6.22	6.19	6.21	.2348		40.2
						6.19	6.23	0.21					40.1
					76.12							.07591	40.1
		20				6.19	6.22	6.20					40.1
						9.19	6.22	6.20	6.18	6.22	.2348		40.05
60.03	76.50	18.8	19.97	60.48		3.46	3.48	3.47	3.42	3.44	.1308		22.5
						3.47	3.49	3.48					22.5
					36.25							.07642	22.3
		18.7	20.07	60.33		3.48	3.49	3.48					22.4
						3.48	3.50	3.49	3.42	3.44	.1308		

straight lines of different slopes, these lines intersecting at the value

$$\frac{1}{\sqrt{\delta r}} = 2.3. \tag{5}$$

In other words the law of corona must be expressed by two equations, one for values of $1/\sqrt{\delta r}$ below 2.3, this equation being

$$\frac{E}{\delta} = 29.84 + \frac{9.93}{\sqrt{\delta r}} \tag{6}$$

and the other for values of $1/\sqrt{\delta r}$ above 2.26, the equation in this case being

$$E = 32.96 + \frac{8.56}{\sqrt{\delta r}}. \tag{7}$$

The sharp change in the slope of the linear relation between E/δ and $1/\sqrt{\delta r}$ finds its explanation in the fact noted above as to the difference of behavior as regards corona formation between positive and negative corona forming wires, or rods. As has already been stated, the form of the law is the same for both positive and negative rods, but the constants of formula (2) are different. This is equivalent to saying that for values of $1/\sqrt{\delta r}$ below 2.26 negative corona appears first and the law is as given by formula (6). For values of $1/\sqrt{\delta r}$ above 2.26 positive corona appears first and the law is as given by formula (7).

All of the measurements leading to these results were made in terms of laboratory standards and by use of the best available equipment and experimental methods. No account is given here of the various experimental difficulties, precautions and calibrations, a complete account of these being given in a forthcoming paper in the *Journal of the American Institute of Electrical Engineers,* May, 1920. The conditions of accuracy are discussed there and show that the foregoing formulæ are probably accurate within an experimental error of considerably better than ½ per cent.

Considered as an instrument for measurement of voltage, it will be noted from Table 1 how definitely the readings repeat themselves. The law of corona, having been determined by the accurate methods outlined above, the corona voltmeter may therefore be used itself as an instrument for the direct measurement of voltage, in fact its calibration is inherent in its dimensions and it becomes a natural secondary standard.

Fig. 8 shows the exterior of a corona voltmeter suitable for measurements of voltage up to 200,000 volts. The accurate measurements referred to above were made with this instrument. It is 9 ft. 10 in. high, of which 3 ft. is in the insulating terminal. The outside diameter is 1 ft. 10 in. An instrument suitable for voltages

up to 300,000 volts and above is now under construction and will shortly be put into operation by a well-known hydro-electric power company.

In operation the corona voltmeter may be used in two ways. *First*, it may be set for any desired value of voltage by adjustment of pressure in the instrument.   In order to do this the temperature
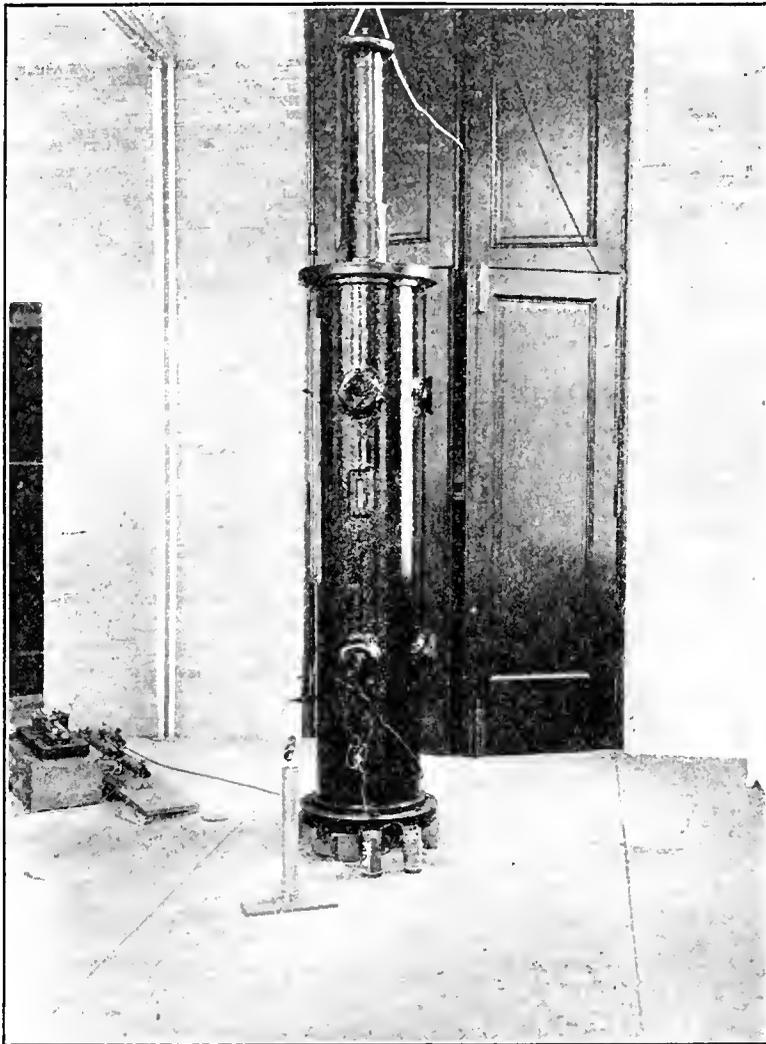
Fig. 8.   Corona Voltmeter for 200,000 volts.

of the air in the instrument is read and the value of the pressure for any desired value of voltage may then be computed from formulæ 3, 6 and 7.   Ordinarily this will be done through reference either to a curve or a table prepared from the formula.   The pressure having been set at the proper value the voltage is then slowly raised until corona appears.   This is the more common

method, as the instrument is chiefly of value in the testing of high voltage apparatus, such as transformers and insulators, in which case it is desirable to apply a definite test voltage as determined by the rating of the apparatus in question.

Second, the corona voltmeter may also be used for measuring an unknown voltage by adjusting the pressure for a value of voltage known to be higher than that to be measured and then gradually lowering the pressure until corona appears.

The instrument as illustrated in Fig. 8 provides a ready means for removing the corona rod either for cleaning or for the substitution of one of a different diameter. A clean rod may be used for many hundred observations without deterioration of its surface.

The corona voltmeter offers many important advantages over existing methods of measuring high voltage. The only other method of direct measurement available is that of the sphere gap or spark between metal spheres. This method is subject to serious error due to the proximity of surrounding objects, and has a different calibration curve for the cases of one sphere grounded and both spheres insulated. It also has the serious disadvantage that it necessitates a spark discharge across the circuit and that the high voltage terminals must be manipulated for each new adjustment. The casing of the corona voltmeter is grounded at all times, and provides a complete electrostatic screening making the instrument free from all types of outside disturbance. It causes no discharge and draws no current from the high voltage terminals. Changes of setting to meet new values of voltage are accomplished merely by changing the air pressure in the instrument. A number of lesser advantages need not be enumerated here.

LABORATORY OF ELECTRICAL ENGINEERING,
JOHNS HOPKINS UNIVERSITY.

A NEW THEORY OF POLYNESIAN ORIGINS.

By ROLAND B. DIXON, Ph.D.

(Read April 22, 1920.)

The problem of the origin and racial affiliations of the Poly-
nesian peoples has engaged the attention of anthropologists for
many years. Struck by their contrast with the black-skinned and
lower cultured populations of Melanesia and Australia, even the
earlier explorers began to speculate as to the provenance of this
attractive and interesting people, and suggestions of an affiliation
with the Malayan peoples of Indonesia were soon made. The
recognition of the linguistic relationship of the various Polynesian
languages to the Malay helped greatly to strengthen this view, and
when the Micronesian and many of the Melanesian languages were
also found to belong to the Malayo-Polynesian family, the founda-
tions of the current theory of Polynesian origins were laid. This
theory accounts for the Polynesian people as a branch of the Malay
which, breaking away from the parent stock, migrated eastward
through Melanesia to the islands further out in the Pacific. The
study of the physical types among the Polynesians and of their cul-
ture seemed to fortify this general conception. Such Melanesian
features as were recognized came to be regarded as due to accul-
turation and mixture with Melanesian peoples in the course of the
eastward migration, for the Polynesians were usually held to have
been the first occupants of the islands in which they were found.
The hypothesis of an earlier stratum of Melanesians throughout the
Polynesian area was indeed advanced, but in general met with little
approval.

As further studies were made on the physical side, it began to
be seen that the Polynesians were really far from being a uniform
type. The presence of several types was recognized, and various
explanations offered to account for the diversity. Some regarded

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these differences as due to social and economic causes, others as the result of different waves of immigrants. For the most part the investigators confined their attention to portions of the field only, studying the Hawaiians or the Maori for example, rather than including all of the Polynesian peoples; and largely relied, furthermore, on averages of measurements and indices for their results. In consequence the situation remained obscure, correlation between different portions of the Polynesian area, and between it and the rest of Oceania was difficult, and while the whole problem was seen to be growing in complexity, no satisfactory general theory was possible.

Having for many years been greatly interested in the whole question of the origins and development of the Oceanic peoples, and having on the basis of existing data, attempted most unsatisfactorily to explain the whole matter to students, the author finally came to the conclusion that only by a revision and reinvestigation of all available data, on somewhat different lines, could the muddle be cleared up. Accordingly, all accessible measurements, not only of Polynesians but of all the people of Oceania together with those of southeastern Asia, were gathered together and analyzed on what, at least for this area, was a novel plan. The final results of the whole study are not yet complete, but the analysis of the Polynesian data has led to such unexpected and interesting, yet at the same time logical and coherent results, that their brief presentation seemed desirable.

Before outlining the conclusions reached, a few words must be said as to the method employed. For the most part in previous studies, attention has been mainly directed to the cephalic index, or if other indices and measurements were considered, little or no attempt was made to study the correlation of these indices in individual skulls. In the present investigation, a correlation was made for the cephalic, length-height and nasal indices, with the addition of the facial index where it was available. Thus the accessible series of Hawaiian crania was analyzed into groups, one comprising all skulls that were for instance Dolichocephalic and at the same time Hypsicephalic and Platyrrhine, another including all that were

Brachycephalic, Hypsicephalic and Platyrrhine; or Mesocephalic, Orthocephalic and Leptorrhine, etc. The assumption was then made (and it was in the beginning a pure assumption) that those groups whose indices were all extremes either at one end or the other of their several series, constituted primitive or fundamental types; while those having one or more of their indices medial in value, were the results of the crossing or blending of the fundamental types. Thus the Dolichocephalic, Hypsicephalic, Platyrrhine group was a fundamental or primitive one, for all three of the indices correlated lay at one extreme or the other of their series; while the Mesocephalic, Orthocephalic, Mesorrhine group (to take the most pronounced example) would be regarded as a blend or derivative type, since its indices in every case, lay half way between the extremes of their series.

The relative proportions of these various fundamental and derived or blended types were then calculated for all of the different island groups in Polynesia—and at once results of much interest became apparent. For in one portion of Polynesia one fundamental type was seen to be dominant, while in another a different one assumed the leading place, and the blends or derived types in each area were found to be clearly explicable as resulting from the fusion of just those fundamental types which were actually present, or whose former presence could logically be assumed. The complexity of the Polynesian population was thus confirmed, but in place of the previous confusion, a rather remarkable degree of order was found to exist, while at the same time the causes of the complexity were revealed in the fusion of the fundamental types present in varying proportions in different parts of the Polynesian area. When, moreover, the same methods of analysis were applied to the data from Melanesia, Micronesia, Australia and Indonesia, and carried on into the eastern portion of the Asiatic continent, it was found that these same fundamental types and their derivatives and no others, made up the population of the vast majority of the population of this whole great area, although the different elements were combined in very different proportions in the various parts of the field. By viewing the problem whole in this way, the conviction

grew that the racial history of the Oceanic area could be logically and satisfactorily explained by a series of waves of fundamental or derived types spreading from west to east throughout the whole area. The theory of a series of successive waves bringing different physical types into Oceania is, of course in no sense new, the novelty of the present results lies in the character and ultimate affiliations of the fundamental types assumed.

We may now turn to the outcome of this present study, so far as it relates to Polynesia. The underlying and probably historically the oldest of the fundamental types in Polynesia is one which, so far as crania alone are concerned, is practically identical with that of the Negrito. This result was so unexpected that at first it was believed that some error had been made; for that a relatively fair, tall people such as the Polynesians, with normally wavy hair, should comprise a substantial factor comparable with the dwarfish, black-skinned and woolly-haired aborigines of the Philippines and the Malay Peninsula, seemed most improbable. Further examination, however, showed that not only was the Brachycephalic, Hypsicephalic, Platyrrhine group in Polynesia the exact equivalent of that which characterized the Negrito in the three correllated indices together with the facial index, but also in the absolute measurements of the head, face and nose as well as in capacity. The identification, therefore, had to be accepted. The geographical distribution of this Negrito type as it may tentatively be called, is significant, but at the same time puzzling, for it survives in any strength only in the Hawaiian Islands, and there seems concentrated in Kauai, the northernmost of the group. The influence of this type in derivative forms, may be traced in most of the other marginal groups in the east and south of Polynesia, but, on the basis of our very scanty data from Tonga and Samoa, seems to be absent in the west.

Second in historical sequence probably, is the Dolichocephalic, Hypsicephalic, Platyrrhine type, whose proximate affiliations lie with the negroid population of Melanesia and Australia. That some element of Melanesian character had entered into the Polynesian complex has long been recognized but has usually been ex-

plained as due to the absorption of a certain amount of Melanesian blood by the Polynesian ancestors, in the course of their migration through or along the margin of Melanesia. The geographic distribution of crania of this type, as shown by the present study, seems to show this view to be practically untenable, and to lead to the conclusion that a stratum of relatively pure Austro-Melanesian type must have preceded the "Polynesians" in Polynesia. For like the Negrito type, this also is marginal in its occurrence, and while the Negrito type survives most strongly in Hawaii in the north, this appears in greatest strength in Easter Is. on the eastern margin of the area. It makes its influence felt in the northern islands of the Hawaiian group, in the Marquesas and Central Polynesia, and plays a notable part in New Zealand. Here, there is interesting evidence to show that one of its most common derivatives, very numerous throughout Melanesia, has played a double rôle, entering into the composition of the Maori people not only at an early date, but reappearing again much later as a relatively recent factor in the make-up of that extremely complex people.

The third and historically clearly the latest type which has contributed to the making of the Polynesian people, and the one whose influence has for long been preponderant over a large part of the area, is one which is Brachycephalic, Hypsicephalic and Leptorrhine. This type is one which forms a very important factor in the rather complex Malayan and Eastern Asiatic populations, but for which I have not as yet found a wholly satisfactory name. In Polynesia, this type seems strongest in Samoa and Tonga in the west, and of great importance in the southern islands of the Hawaiian group, while it plays a considerable part in Central Polynesia and New Zealand. Curiously, little trace of it occurs in Easter Island to the east.

Although these three fundamental types and their derivatives or blends comprise the great majority of the Polynesian population, the indications of the presence of a small minority of a fourth fundamental type, must not be overlooked; for although it itself survives only in very small proportions, some of its derivatives are not unimportant in Hawaii and New Zealand. This is a Dolichocephalic,

Hypsicephalic, Leptorrhine type, whose affiliations may be said, for lack of a better term, to be distinctly Caucasic. Its marginal distribution in the north and south, leads to the conclusion that its position is early rather than late in the historical sequence, and there is much to suggest its appearance in company with the Austro-Melanesian stratum.

It must not be understood for a moment, that the present theory would claim that the various primitive and fundamental types came into Poylnesia as pure types, and that all the manifold blends have originated only after arrival. On the contrary, much blending and crossing must have occurred before any of these types even entered the Oceanic area, and much more en route. Yet it is believed that the successive waves or streams although more or less complex in their make up before reaching Polynesia, nevertheless contained in each case a considerable core of pure types. In no other way can the relative abundance of such pure types in the extreme marginal portions of Polynesia, be easily accounted for.

It is in the highest degree unfortunate that we have practically no measurements or descriptive data in regard to the living population of this region. For we have in consequence no means of knowing whether skin color, hair and stature are more or less definitely correlated with the cranial types defined. That there were great differenecs in all of these three features, however, we know from the general accounts given by the earlier explorers, the presence in particular of distinctly negroid individuals being frequently mentioned. Such statements thus greatly strengthen and confirm the belief in the complexity of the racial origins of the Polynesian people.

In summary it may be said that the investigation made seems to show that the racial history of the Polynesian area is even more complex than it has hitherto been supposed to be. The underlying stratum here, as well as further westward, appears to be indistinguishable from the Negrito, although the problem of how it reached this remote region is not yet wholly clear. This stratum was followed by a wave of negroid peoples whose most numerous modern representatives in this portion of the world form the bulk of

the population of Melanesia and Australia. As a result of this influx, the earlier Negrito type was largely absorbed, and survives today as such, only in remote marginal areas into which it was driven by the negroid immigrants. Following the negroid came the Malayoid or Mongoloid wave, which, spreading over the area, absorbed and apparently quite submerged the preceding types and blends in western Polynesia, and flooded in force into the central, southern and northern portions, so that the Austro-Melanesian or negroid type and its predecessor were left in any degree intact, only in the marginal areas. These successive waves must not, however, be thought of as rapid conquests, but rather, for the most part, as slow drifts requiring generations or centuries for their completion, with periods of halting, and as following moreover somewhat different paths.

For much of the Polynesian area, the available data are extremely scanty, and conclusions must therefore be regarded as only tentative. It is encouraging to learn that much fuller materials are probably soon to be made accessible, as a result of the expeditions to be sent out by the Bishop Museum in Honolulu beginning this present summer. An analysis of this expected large body of material, on the plan here followed will, it is believed, confirm and greatly amplify the general conclusions reached.

HARVARD UNIVERSITY,
April, 1920.

COLLECTING STATIONS

IN THE DRAINAGES

OF THE

OHIO

AND

TENNESSEE RIVERS

SCALE

0   25   50   75   100
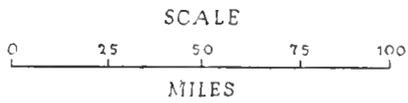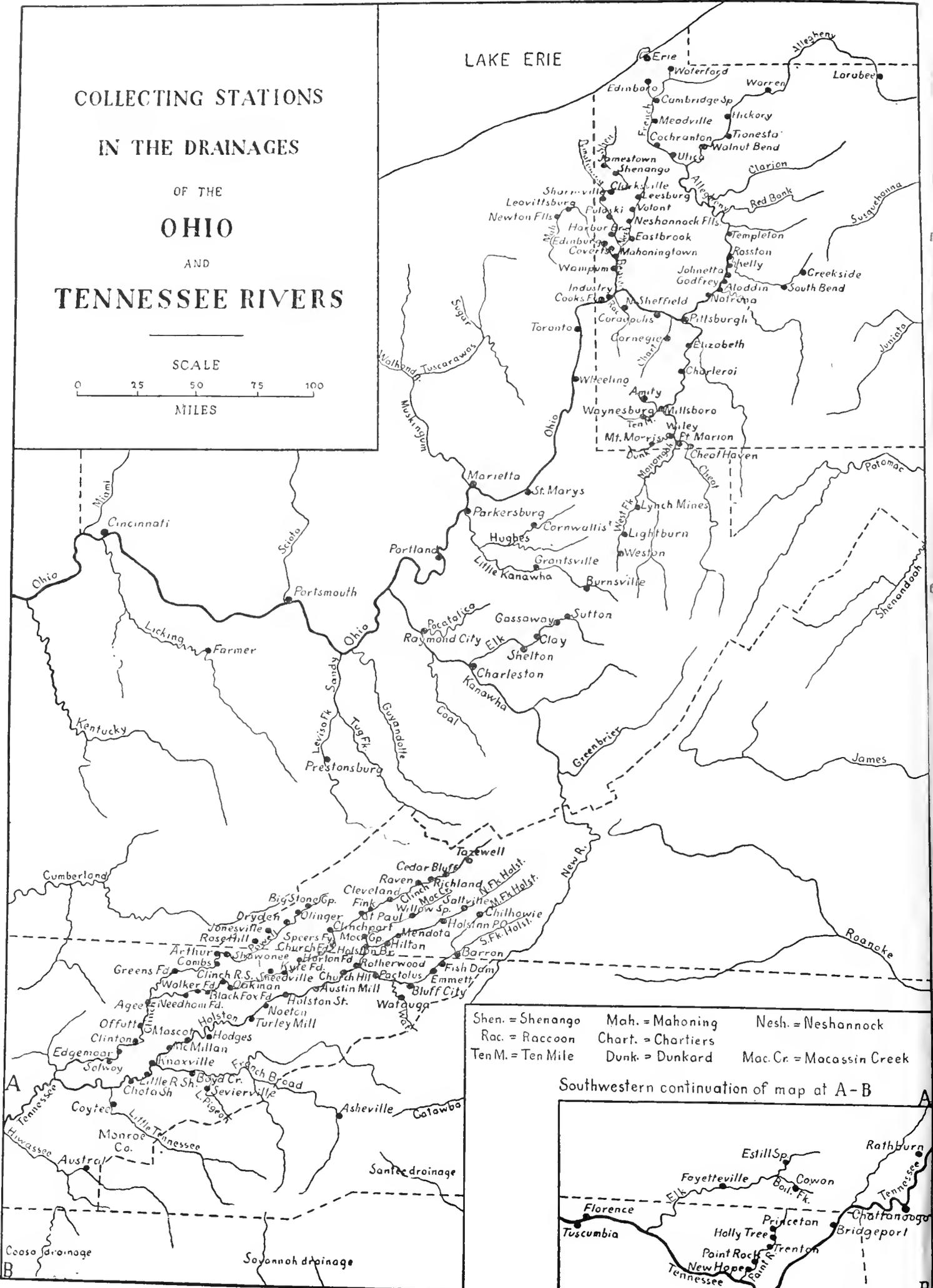
MILES

Shen. = Shenango   Mah. = Mahoning   Nesh. = Neshannock
Rac. = Raccoon   Chart. = Chartiers
Ten M. = Ten Mile   Dunk. = Dunkard   Moc. Cr. = Macassin Creek

Southwestern continuation of map at A-B
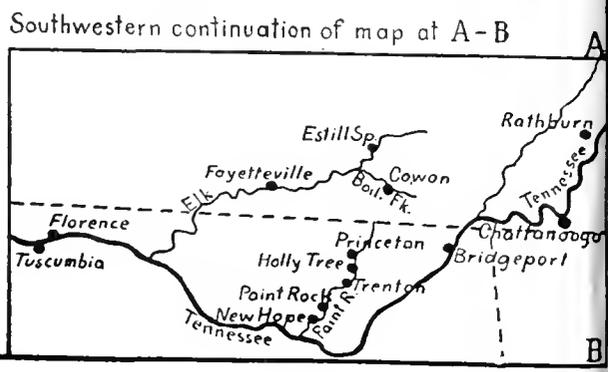
CORRELATION OF SHAPE AND STATION IN FRESH-WATER MUSSELS (NAIADES).

By A. E. ORTMANN, Ph.D.

(Read April 24, 1920.)

While studying the Naiad-shells of the upper Ohio-drainage, the fact was forced upon my mind, that certain species which inhabit the headwaters and smaller streams are represented, in the larger streams, by different, but very similar forms, which are distinguished from them chiefly by one character, namely obesity. The headwaters-forms are rather compressed or flat, the large-river-forms more convex and swollen. I also found that in the rivers of medium size integrades betwen the extremes were actually present.

Subsequently, similar conditions appeared to prevail elsewhere, and the existence of this rule was brought home to me very forcibly during my study of the Naiad-fauna of the upper Tennessee drainage.

Also other authors have observed this fact, and have referred to it in their publications. Thus Wilson and Clark[1] indicated it for certain species of the Cumberland River (*Amblema peruviana* and *costata; Rotundaria tuberculata* and *granifera; Dromus dromas* and *caperatus*) and Utterback[2] has found this law to hold good in Missouri (chiefly in the Osage River) for several species (*Fusconaia undata* and *trigona; Amblema peruviana* and *costata; Pleurobema obliquum* and allied forms).

I myself have alluded to this relation between a compressed headwaters-form and a swollen large-river-form in the case of *Obovaria lens* and *subrotunda,*[3] in the case of *Pleurobema coccineum*

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[1] Bur. Fisher. Doc. no. 781, 1914, pp. 21 and 63.

[2] *Amer. Midl. Natural.,* 4, 1916, p. 2.

[3] *Ann. Carn. Mus.,* 5, 1909, p. 192.

and *obliquum*[4] and in the case of the group of *Fusconaia barnesiana*.[5] I have given a fuller account, including the synonymy of the forms concerned. Additional references may be found in my paper on the upper Tennessee shells[6] and on the Pennsylvanian Naiades.[7]

However, all this information is rather vague, and not supported by detailed measurements, and, before we finally assume that this law exists at all, we should substantiate it by more careful investigations. The present paper is written with the purpose to supply the details and to reduce them to figures.

When we speak of the *obesity* of mussel shells, and call them *flat* and *compressed,* or *convex* and *swollen,* we refer to the proportional *diameter* of the shell. This diameter can be expressed in various ways, but I found that the most easy is in percentage of the length. The length is always measured parallel to the ligament,[8] which can be done, without difficulty, by placing the shell between the arms of a vernier caliper measure in the proper position. The diameter is measured at right angles to it, and always the maximum diameter of the two valves is taken, no matter where it is located. The length is then taken as $= 100$, and the diameter expressed in hundredths of the length.

The material studied has been collected, for the largest part, by myself, and thus I am able to vouch for the correctness of the localities. It forms part of the collections of the Carnegie Museum in Pittsburgh. Yet there is additional material from other sources. The Carnegie Museum possesses a fine collection from the Tennessee drainage in northern Alabama and southern Tennessee made by H.

[4] *Nautil.,* 23, 1910, p. 117, footnote 2, and *Ann. Carnegie Mus.,* 8, 1912, p. 264.

[5] *Nautil.,* 31, 1917, p. 58.

[6] *Proc. Amer. Philos. Soc.,* 57, 1918, p. 521 ff.

[7] *Mem. Carnegie Mus.,* 8, 1919.

[8] The *greatest* length of the shell is sometimes in a diagonal direction, when the shell is "oblique"; but since the obliquity varies much individually, the length parallel to the ligament is selected. Previous authors (Lea for instance) have not strictly adhered to this rule, and thus we may explain certain discrepancies of the figures given in his text, and those taken from his illustrations. In my measurements, I have always taken Lea's illustrations as the standard.

H. Smith; and finally I had the privilege of examining upper Tennessee shells in the collection of Mr. B. Walker in Detroit, collected by C. C. Adams (particulars about these may be found in my paper on the upper Tennessee Naiades).

Of course, the shells collected at one and the same locality vary somewhat, and thus it was necessary to compute the average for each set. In some cases, only few specimens were at hand, in others, a great many of them. Thus I do not give, in the tables, the individual measurements, but only the extremes and the average. We shall see that this is entirely sufficient to establish the law. In each river, the localities are arranged from downstream upward, taking up the tributaries of the main stream generally in ascending order. The exact situation of each locality may be found on the map (page 258).

According to obesity, previous authors frequently have distinguished separate species, and often corresponding forms in different river-systems have received different specific names. Thus it has been a difficult task to bring order in the nomenclature, and I am compelled to devote considerable space to this. Since it will become apparent that the various groups of forms treated actually are *connected by intergrades,* each group should be regarded, taxonomically, as *one species.* But since, on the other hand, the extremes are often rather sharply contrasted, and since they very generally appear as geographical (or rather ecological) races, it is convenient and justified, to use the old specific names in a varietal (or subspecific) sense. On account of the existing intergrades it is difficult, even impossible, to draw sharp lines between these varieties, and the dividing lines selected by myself (according to per-centage of diameter) may seem, and are, arbitrary: I have endeavored, in this respect, to preserve the older names as far as possible. Sometimes it was possible to distinguish only two forms, a swollen one and a flat one; in other cases, three have been admitted (an intermediate one being added to the two extremes). This latter course was made necessary in those instances, where the oldest name was given to an intergrading form.

GROUP OF FUSCONAIA SUBROTUNDA IN THE UPPER OHIO SYSTEM.

The following is the taxonomy of this group here accepted.

1. FUSCONAIA SUBROTUNDA (Lea).—Dia. 50 per cent. of length and over.

Unio subrotundus Lea. '31 (Ohio).—*Quadrula subrotunda* Simpson, '14, p. 892.[9]

Dia. (Lea): 60 per cent. Simpson gives: 44, 49, 51 per cent., but only the last one would belong here according to the definition accepted above.

Unoi politus Say, '34.—Synonym to *subrotunda* according to Simpson.

Dia. (Conrad, '37): 53 per cent.

Fusconaia leucogona (pars) Ortmann, Nautil. 27, '13, p. 89 (Elk River, W. Va.).

2. FUSCONAIA SUBROTUNDA KIRTLANDIANA (Lea).—Dia. less than 50 per cent.

Unio kirtlandianus Lea, '34 (Mahoning R., Ohio).—*Quadrula kirtlandiana* Simpson, '14, p. 891.

Dia. (Lea): 44 per cent.; (Simpson): 33, 38 per cent.

Fusconaia leucogona (pars) Ortmann, l. c.

Measurements taken from My Material.[10]

Loc.	No.	Max.	Min.	Av.	
Ohio River.					
Portsmouth	5	67	51	59	*subrot.*
Portland	4	52	49	51	*subrot.* (*kirtl.*)
Parkersburg	1	51	51	51	*subrot.*
St. Mary's	8	62	50	54	*subrot.*
Toronto	2	52	50	51	*subrot.*
Cooks Ferry	2	54	52	53	*subrot.*
Industry	9	57	42	47	*kirtl.* (*subrot.*)
Coraopolis	8	53	42	48	*kirtl.* (*subrot.*)

[9] Simpson, C. T. A descriptive Catalogue of the Naiades, or Pearly Fresh-water Mussels. Detroit, 1914. All other references given without detil may be found in this work.

[10] The first column gives the locality; the second the number of specimens at hand; the third, fourth and fifth, the maximum, minimum, and average of the percentage of the diameter; and in the last column, the name of the variety represented is given. When several forms are present, the first name is that of the prevailing (average) form, the other (in parenthesis) that of the less abundant one.

Thus it appears that in the Ohio, between Portsmouth and Pittsburgh, there is a tendency to decrease the diameter in the upstream direction. The most swollen specimens, with the highest diameter, and the highest average of it, have been encountered at the lowermost station (Portsmouth), and the most compressed specimens, and the lowest average, at the two uppermost stations. This general law holds good also, when we now go up the *Allegheny River,* and enter *French Creek.* (In the Allegheny proper, above the mouth of French Creek, this species has not been found.)

Loc.	No.	Max.	Min.	Av.	
Allegheny River.					
Natrona	I	45	45	45	*kirtl.*
Aladdin	3	47	45	46	*kirtl.*
Godfrey	26	66	43	51	*subrot.* (*kirtl.*)
Johnetta	2	50	46	48	*kirtl.* (*subrot.*)
Kelly	113	54	38	47	*kirtl.* (*subrot.*)
Templeton	I	49	49	49	*kirtl.*
French Creek.					
Utica	4	43	40	42	*kirtl.*
Cochranton	8	49	33	42	*kirtl.*
Meadville	2	46	45	45.5	*kirtl.*
Cambridge Springs	2	44	43	43.5	*kirtl.*

Here we notice irregularities, indeed, in so far as, for instance at Godfrey, the percentage increases again, and remains only a little below 50 per cent. in the Allegheny, but sinks rather abruptly to a little above 40 per cent. in French Creek. The latter phenomenon may be due to the sudden decrease in the size of the streams. It should also be noticed that both the maxima and minima decrease in the upstream direction, and it always should be emphasized that the material from the various localities is not uniform as regards the number of specimens measured: thus irregularities should be encountered, and, of course, mathematical exactness cannot be expected in a biological object.

Taking all the shells together, beginning in the Ohio at Portsmouth, and going up the Allegheny to French Creek, we notice *the general decrease of the obesity:* the most swollen specimen was found at Portsmouth (67 per cent.) ; the most compressed one (33 per cent.) in French Creek. Specimens from the lower parts of the

Ohio have a diameter almost uniformly above 50 per cent.; in the region around Pittsburgh (in Ohio and Allegheny), it varies around 50 per cent.; and in French Creek it falls below 45 per cent. (always barring minor irregularities).

Already this first instance substantiates the general law propounded in the introduction: *in the larger rivers, these shells are more convex and swollen; in the headwaters, they are flat and compressed; and in the intermediate parts, the intergrades between the extremes are found.*

Under these circumstances it is, indeed, hard to draw a line between the two forms called *subrotunda* and *kirtlandiana*. According to measurements taken from Lea (Dia. 69 per cent.), there are specimens which are even more obese than any of those examined by myself (max. 67 per cent.), and these swollen forms differ very strikingly from those which have only 44 per cent. (as in Lea's type of *kirtlandiana*), or even less (falling to 33 per cent. according to Simpson and my material). In order to include *politus* Say in the synonymy of *subrotunda,* as Simpson has done, I have decided to draw the line at the diameter of 50 per cent., so that individuals with this diameter and over shall be called *Fusconaia subrotunda,* and individuals with the diameter less than 50 per cent. shall be called *Fusmonaia subrotunda kirtlandiana.* Thus it is evident that two of the shells of *subrotunda,* for which Simpson gives the measurements, having the diameter 44 and 49 per cent., fall under *kirtlandiana.*

This will bring almost all specimens in the Ohio below Pennsylvania under the main species, while all specimens in French Creek are the var. *kirtlandiana.* In the Pennsylvanian part of the Ohio, and in the Allegheny, we have the two forms associated, sometimes the one, sometimes the other prevailing, and the various sets from these localities should be separated accordingly. This is only what we should expect as the natural condition; and also, for practical purposes, this clears matters up, and brings sets together, which are rather uniform.

One additional circumstance should be pointed out. *The obesity of the shell changes a little with age, so that young shells, in the*

average, are more swollen than old ones. This does not, however, introduce a serious error, since from most localities young and old shells are at hand. On the other hand, this serves to explain, in part, the irregularities observed. Very old shells are often unusually produced or elongated at the posterior end, and this tends to lower the percentage of the diameter. Just such shells have been found frequently in the Ohio near Pittsburgh, and these have, consequently, unduely depressed the average. Also the young shells, or, for that matter, shells of about the same size, when compared among themselves, show the decrease of the obesity in the upstream direction. The same phenomenon is found in other forms to be discussed later.

Fusocnaia subrotunda also enters several tributaries of the Ohio. First of all, we have it in Elk River in West Virginia (tributary to Kanawha). The Kanawha empties into the Ohio in a region where typical *subrotunda* is found. I have no material from this river. But in Elk River is a form, which I have called *F. subrotunda leucogona,* and which I have characterized as a " rather small and somewhat flattened *subrotunda,"* also differing by (mostly) pale soft parts and eggs. I doubt now the propriety of introducing a separate name for this form, for it might very well be included under both, *subrotunda* and *kirtlandiana,* these also having sometimes pale soft parts. The following table gives the measurements of the *Elk River* specimen.

Loc.	No.	Max.	Min.	Av.		
Shelton	12	52	45	49.5	*kirtl.*	(*subrot.*)
Gassaway	12	53	38	48	*kirtl.*	(*subrot.*)
Sutton	12	49	43	46	*kirtl.*	

The decrease of the average diameter is also here clearly shown, the maximum being found in the two lower stations (with specimens which would fall under *subrotunda*). The minimum has been observed in the middle station, but only in one individual, and another with the diameter of 41 per cent., while all the rest do not fall under 45 per cent. This is one of the irregularities which should be expected.

Another river which contains this species is *Beaver River* in

Pennsylvania. This is formed by two main branches, *Shenango* and *Mahoning*, which unite below Newcastle, at Mahoningtown. I shall begin with the only locality in the Beaver proper, then go up the Shenango to the mouth of Pymatuning Creek, and finally go up the Mahoning.

Loc.	No.	Max.	Min.	Av.	
Beaver River.					
Wampum	25	52	41	44	*kirtl.* (*subrot.*)
Shenango River.					
Harbor Bridge	13	47	36	40	*kirtl.*
Pulaski	18	49	40	44	*kirtl.*
Sharpsville	4	48	35	43	*kirtl.*
Clarksville	18	50	36	45	*kirtl.*
Pymatuning Creek (mouth)	1	39	39	39	*kirtl.*
Mahoning River (follows Wampum).					
Mahoningtown	51	52	37	44	*kirtl.* (*subrot.*)
Coverts	6	47	40	43	*kirtl.*
Edinburg	4	42	39	40	*kirtl.*

In the Ohio, just below the mouth of the Beaver (at Industry), the diameter is 47 per cent. Thus the Beaver-shells are clearly less swollen. While all these specimens are rather uniform in diameter, it is seen that the lowest average is farthest upstream. Specimens with over 50 per cent. are found frequently only at the lowermost stations (Wampum and Mahoningtown), and specimens with lowest diameter (below 40 per cent.) are most frequent farther up. The very high average at Clarksville (45 per cent.) is due to an unusual number of young specimens, which, as we have seen, tend to elevate the average; and the low average at Harbor Bridge is due to the fact that mostly large specimens are among them, which depress the figures.

It should be mentioned that the type-locality for *kirtlandiana* is in the " Mahoning River, Ohio," that is to say, farther up than any of my localities, and that the diameter as given by Lea's illustration is 44 per cent.

Thus nearly all of the shells from the Beaver drainage fall under *kirtlandiana*.

Finally, I have shells belonging here from the *Monongahela drainage*. At present, the Monongahela in Pennsylvania and parts

of West Virginia (below Clarksville) is polluted, and its fauna is destroyed. I have older material, however, from one locality in the Monongahela proper; farther up, I collected some near the mouth of *Cheat River,* just at the state line; and at one locality in the headwaters (*West Fork River*). The measurements are as follows.

Loc.	No.	Max.	Min.	Av.	
Monongahela, Charleroi	13	61	48	53	*subrot.* (*kirtl.*)
Cheat, Cheat Haven	2	52	40	46	*kirtl.* (*subrot.*)
West Fork, Lynch Mines	2	44	41	42.5	*kirtl.*

This material is rather scanty; nevertheless the decrease in obesity in the upstream direction is clearly seen. The locality Charleroi has a higher percentage (63) than the next localities below in the Ohio (47 and 48 at Industry and Coraopolis), but agrees with that of Cooks Ferry. This, probably, is again due to the age of the shells. In the Ohio below Pittsburgh, giant specimens, with the length over 100 mm., are not uncommon, while among the shells from Charleroi there is not a single one over 100 mm. (largest 91 mm.).

Very probably, this law holds good also in other tributaries of the Ohio. I have not enough material to demonstrate this. In one case, that of the *Tuscarawas River* in Ohio, I have rather abundant material from the Holland collection, but, unfortunately, no exact localities are given; both forms, however, are represented in this river. From the *Levisa Fork Big Sandy River,* Prestonsburg, Floyd Co., Ky., I have a single specimen, the diameter of which is 50 per cent., that is to say, it is a *subrotunda* standing just at the lower limit, and close to *kirtlandiana,* and this would correspond to the station well up the river. From *Little Kanawha River*, Grantsville, Calhoun Co., W. Va., I have one specimen, the diameter of which is 43 per cent. this is the typical *kirtlandiana*, corresponding to the small size of this river.

All this serves to show that our contention is upheld, *that F. subrotunda and kirtlandiana are forms of the same species, differing only in obesity.* The former is the swollen form of the large rivers; the latter is the compressed form of the small streams. Both

are connected by intergrades, and any line drawn between them must necessarily be artificial and arbitrary. It is advisable, however, to retain the old names in a varietal sense, for the extremes are rather strikingly different.

GROUP OF FUSCONAIA PILARIS IN THE UPPER TENNESSEE-DRAINAGE.

Fusconaia pilaris (Lea) is the representative of *F. subrotunda* in the upper Tennessee system, and it is extremely hard to distinguish the two. All I can say is that *pilaris* is a smaller shell than *subrotunda*, a character mentioned also by Simpson. For the rest, there is no difference, and it is actually impossible to tell younger *subrotunda* from *pilaris*, as is shown by the fact that *pilaris* repeatedly has been reported from the Ohio River. In the Tennessee River in northern Alabama, typical *subrotunda* is found, and I have specimens from this region. But since I have no material from this river between these parts and the vicinity of Knoxville, Tenn., I cannot discuss the relation of these two forms. They may pass into each other.

The *pilaris*-group of the upper Tennessee contains a number of nominal species which have been distinguished on entirely insufficient grounds. I have revised them[11] in the following way.

1. FUSCONAIA PILARIS (Lea).—D. 55 per cent. or over.

Unio pilaris Lea, '40 (French Broad and Holston).—*Quadrula pilaris* Simpson, '14, p. 893.

Dia. (Lea) : 63 per cent. Simpson gives two measurements, 47 and 54 per cent., which, however, belong to the next form, which he unites with this.

Unio globatus Lea, '71 (Holston).—*Quadrula globata* Simpson, '14, p. 899.

Dia. (Lea) : 68 per cent.; (Simpson) : 67 per cent.

Quadrula andrewsæ Marsh, '02 (Holston).—*Quadrula andrewsi* Simpson, '14, p. 895.

Dia. (Simpson) : 55 per cent.

[11] *Proc. Amer. Philos. Soc.*, 57, '18, pp. 527–529.

Quadrula beauchampi Marsh, '02 (Little Tennessee and Holston).—
Simpson, '14, p. 895.
Dia. (Simpson): 61 per cent.

2. FUSCONAIA PILARIS LESUEURIANA (Lea).—Dia. 45–54 per cent.

Unio lesueurianus Lea, '40 (Caney Fork and Holston).—Synonym to *pilaris*, according to Simpson.
Dia. (Lea): 51 per cent.—Simpson's measurements of *pilaris* (47 and 54) belong here.
Quadrula flexuosa Simpson, '00 (Holston).—Simpson, '14, p. 887.
Dia. 51 per cent.

3. FUSCONAIA PILARIS BURSA-PASTORIS (Wright).—Dia. less than 45 per cent.

Unio bursa-pastoris Wright, '96 (Powell R., Va.).—*Quadrala bursa-pastoris* Simpson, '14, p. 890.
Dia. (Simpson): 35 per cent.

I shall follow the same scheme as before, and go up the Tennessee and the tributaries: Holston, Clinch, Powell, etc.

Loc.	No.	Max.	Min.	Av.	
Tennessee River.					
Knoxville	8	64	53	57	*pil.* (*les.*)
Holston River.					
McMillan	1	50	50	50	*les.*
Mascot	16	63	47	56	*pil.* (*les.*)
Hodges	2	53	51	52	*les.*
Turley Mill	4	56	43	47	*les.* (*pil.*) (*b.-p.*)
Noeton	7	60	48	51	*les.* (*pil.*)
Holston Station	7	54	47	51	*les.*
Church Hill	3	47	43	45	*les.* (*b.-p.*)
South Fork Holston River.					
Pactolus	10	49	39	45	*les.* (*b.-p.*)
Bluff City	5	45	39	42	*b.-p.* (*les.*)
Watauga River.					
Watauga	1	40	40	40	*b.-p.*
North Fork Holston River.					
Rotherwood	7	54	44	50	*les.* (*b.-p.*)
Holston Bridge	1	46	46	46	*les.*
Hilton	9	48	41	43	*b.-p.* (*les.*)
Mendota	1	38	38	38	*b.-p.*

It is interesting to observe that all three forms are found at Turley Mill.

This table shows that the diameter decreases in the upstream direction. There are slight irregularities, but the general law is distinctly expressed.

In the *Clinch River,* this is shown even more distinctly. The Clinch goes into the Tennessee below my lowermost locality at Knoxville, but my first station in the Clinch is a good distance up from the mouth.

Loc.	No.	Max.	Min.	Av.	
Clinch River.					
Solway	12	59	44	51	*les.* (*pil.*) (*b.-p.*)
Edgemoor	17	62	44	52	*les.* (*pil.*) (*b.-p.*)
Clinton	9	56	40	48	*les.* (*pil.*) (*b.-p.*)
Offutt	7	53	43	47	*les.* (*b.-p.*)
Agee	1	46	46	46	*les.*
Needham Ford	14	53	36	44	*b.-p.* (*les.*)
Black Fox Ford	6	45	36	40	*b.-p.* (*les.*)
Clinch River Station	5	44	35	40	*b.-p.*
Oakman	7	44	37	40	*b.-p.*
Sneedville	1	36	36	36	*b.-p.*
Kyle Ford	2	45	40	42.5	*b.-p.* (*les.*)
Horton Ford	1	37	37	37	*b.-p.*
Speers Ferry	3	40	38	39	*b.-p.*
Clinchport	12	46	35	40	*b.-p.* (*les.*)
St. Paul	3	38	36	37	*b.-p.*
Fink	2	41	40	40.5	*b.-p.*
Cleveland	7	37	34	36	*b.-p.*
Raven	11	40	33	36	*b.-p.*
Richland	10	41	35	37	*b.-p.*
Cedar Bluff	5	39	34	37	*b.-p.*

Powell River (Agee, just below has 46 per cent. = *les.*).

Loc.	No.	Max.	Min.	Av.	
Greens Ford	2	49	42	45.5	*les.* (*b.-p.*)
Combs	8	45	35	39	*b.-p.* (*les.*)
Arthur	4	44	34	40	*b.-p.*
Shawanee	4	49	38	42.5	*b.-p.* (*les.*)
Rose Hill	2	41	40	40.5	*b.-p.*
Jonesville	1	39	39	39	*b.-p.*
Dryden	3	43	36	39	*b.-p.*
Big Stone Gap	1	39	39	39	*b.-p.*

These tables do not need any further comment: barring certain local irregularities, which can be accounted for by scarcity of material, the law is clearly shown, that in the upstream direction the diameter decreases, and that it decreases very gradually. The conditions in the Holston, and chiefly in the Clinch and Powell are, indeed, classical.

It should be added that I have seen a single individual from *Little Tennessee River*, Coytee, Loudon Co., Tenn., which has the diameter of 58 per cent. (= *pilaris*). Little Tennessee goes into the Tennessee below Knoxville, and thus this agrees well with the figure for specimens from Knoxville (57 per cent.).

I further collected a large number of specimens in *French Broad River*, at Boyd Creek, Sevier Co., Tenn. This river unites with the Holston to form the Tennessee just above Knoxville. I have measured 16 specimens; the max. is 64 per cent.; the min. 47 per cent.; the av. 56 per cent. Also these figures are exactly what we should expect.

There is no question that all these shells are one and the same species, for which the name *pilaris,* as the oldest, should be used, and which changes in obesity from the large rivers towards the headwaters. Since Lea distinguished, at the same time, two forms which differ chiefly in being more or less swollen, the two names given by him (*pilaris* and *lesueuriana*) should be preserved in a varietal sense, and a third variety of great compression should be added, described much later by Wright as *bursa-pastoris.*

As *pilaris* corresponds to *subrotunda, bursa-pastoris* corresponds to *kirtlandiana* of the upper Ohio drainage. In fact, it is so close to it that Pilsbry and Rhoads[12] have identified specimens from *Watauga River* as *kirtlandiana.* I have serious doubts that the two forms can be kept apart, when the locality is unknown. In my large material I can see only one difference, that is, that *bursa-pastoris* is a smaller shell than *kirtlandiana,* and reaches a greater degree of compression. This opens a very pertinent question as to nomenclature, since also *pilaris* (and *lesueuriana*) apparently represent only a small race of *subrotunda.* I shall not go any further

[12] *Pr. Ac. Nat. Sci., Philad.,* 48, 1896, p. 502.

into this problem, which may necessitate some radical changes in our Naiad-nomenclature.

This much is certain, that *F. pilaris*, the representative form in the upper Tennessee of *F. subrotunda* from the Ohio, behaves exactly as *F. subrotunda*, but the headwaters-forms of the two, in the upper Tennessee and the upper Ohio drainages, although very similar, have no direct genetic connection, and undoubtedly have developed independently of each other.

GROUP OF FUSCONAIA FLAVA IN THE UPPER OHIO-DRAINAGE.

I classify the forms belonging here as follows.

1. FUSCONAIA FLAVA (Rafinesque).—Dia. less than 55 per cent.
Obliquaria flava Rafinesque, '20 (trib. of Kentucky, Salt, Green R.).
—*Quadrula flava* Vanatta, Pr. Ac. Philad., '15, p. 557.
Dia. (Conrad, '37): 43 per cent.; (Vanatta): 39 per cent.
Unio rubiginosus Lea, '29 (Ohio).—*Quadrula rubiginosa* Simpson, '14, p. 872.
Dia. (Lea): 44 per cent.; (Simpson): 41, 34, 53 per cent.

2. FUSCONAIA FLAVA TRIGONA (Lea).—Dia. 55 per cent. and over.
Unio trigonus Lea, '31 (Ohio R., Cincinnati and Louisville).—
Synonym to *Quadrula undata* (Barnes), according to Simpson, '14, p. 881.
Dia. (Lea): 63 per cent.

Probably also *U. undatus* Barnes, '23, belongs here. This form has been discussed by Walker (Nautil., 24, '10, p. 24), who says that it is the same as *trigonus*. He gives the diameter of 68 per cent. Simpson (l. c.), who follows him, gives it as 60, 61, and 76 per cent.

Walker and Simpson probably are right in regarding *trigonus* and *undatus* as synonyms, as far as it concerns obesity. However, I think that they differ in the development of the beaks, *undatus* having higher beaks, so that the outline is more triangular, while it is subtrapezoidal in *trigonus*. Of typical *undatus* I have no good material, and this form is not found in the upper Ohio. What I have from this region (vicinity of Pittsburgh and upwards) repre-

sents, in the more obese form, distinctly the shell called by Lea *trigonus*, and thus I shall use this name, and restrict myself to the two forms *flava* and *trigona*, and their interrelation, leaving the decision as to the standing of *undata* to further investigation. According to Utterback,[13] the latter also passes into *trigona*.

Loc.	No.	Max.	Min.	Av.	
Ohio River.					
Coraopolis	14	63	49	54	*flav. (trig.)*
Monongahela River.					
Elizabeth	1	49	49	49	*flav.*
Charleroi	8	66	50	56	*trig. (flav.)*
Millsboro	1	47	47	47	*flav.*

The following are tributaries going into the Monongahela at and above Millsboro.

Loc.	No.	Max.	Min.	Av.	
N. Fork Ten Mile Creek, Amity..	2	48	48	48	*flav.*
S. Fk. Ten Mile Cr., Waynesburg	6	48	41	44	*flav.*
Dunkard Creek, Wiley	2	47	43	45	*flav.*
Dunkard Creek, Mt. Morris	10	50	41	47	*flav.*

The law is again apparent here: the most compressed forms are found in the tributaries, the most swollen ones in the larger river.

Going up the *Allegheny River*, and ascending one of its tributaries, *Crooked Creek*, the law is not so clearly shown for the reason that this form is rare in the Allegheny proper, and is entirely missing in the headwaters. Yet indications are seen in Crooked Creek.

Loc.	No.	Max.	Min.	Av.	
Allegheny River.					
Godfrey	3	44	41	43	*flav.*
Johnetta	2	55	50	53	*flav. (trig.)*
Kelly	2	42	42	42	*flav.*
Crooked Creek.					
Rosston	29	51	38	43	*flav.*
South Bend	2	41	41	41	*flav.*
Creekside	8	44	38	41	*flav.*

That the compressed form is the one found in smaller streams, is also shown by several isolated sets from other tributaries of the Ohio, which have been measured, and the following are of interest.

[13] *Amer. Midland Naturalist* (Notre Dame, Ind.), 4, '16, p. 21.

Loc.	No.	Max.	Min.	Av.	
Little Kanawha River, Burnsville.	12	55	40	44	*flav.* (*trig.*)
Raccoon Creek, New Sheffield ...	9	46	42	43	*flav.*
Chartiers Creek, Carnegie	3	46	40	44	*flav.*

Since the compressed form of the headwaters (*flava*) very gradually passes into the more swollen form of the larger rivers (*trigona*), the distinguishing line between them necessarily must be arbitrary. I have adopted 55 per cent. as the limit, so that shells with the diameter of 55 per cent. and over are called *trigona,* while shells with less than 55 per cent. are *flava.*

Group of Fusconaia cuneolus in the Upper Tennessee-System.

Fusconaia flava and *trigona* are absent in the upper Tennessee-drainage, but they are represented there by two allied species, which agree in general shape and in anatomy with the Ohio shells, but differ from them, and from each other, chiefly in the color of the epidermis. They appear to be good species, for they do not run into the *flava*-type anywhere, and I also have never found evidence that they run into each other. These shells are *F. cuneolus* and *F. edgariana.* In both of them, however, the same phenomenon as regards obesity is observed.

F. cuneolus has the following forms and synonyms.[14]

1. Fusconaia cuneolus (Lea).—Dia. less than 50 per cent.
Unio cuneolus Lea, '40 (Holston R.).—*Pleurobema cuneolus* Simpson, '14, p. 743.
    Dia (Lea) : 43 per cent. ; (Simpson) : 42 and 46 per cent.

2. Fusconaia cuneolus appressa (Lea.)—Dia. 50 per cent. or over.
Unio appressus Lea, '71 (Tennesse R., Tuscumbia ; Holston R.).—*Pleurobema appressa* Simpson, '00, p. 749.
    Dia. (Lea) : 52 per cent.
Unio tuscumbiensis Lea, '71 (Tuscumbia ; Holston R.).—*Pleurobema tuscumbiensis* Simpson, 14, p. 748.
    Dia. (Lea) : 56 per cent. ; (Simpson) : 56 and 58 per cent.

[14] See *Pr. Amer. Philos. Soc.,* 57, '18, pp. 530, 531.

Unio flavidus Lea, '72 (Clinch R., Anderson Co., Tenn.; Holston
  R.; N. Ala.).—Synonym to *Pl. tuscumbiensis*, according to Simp-
  son, l. c.

  Dia. (Lea) : 52 per cent.

  I have measured the following material.

Loc.	No.	Max.	Min.	Av.	
Tennessee River.					
Chota Shoals	4	66	51	61	*appr.*
Holston River.					
Turley Mill	1	46	46	46	*cun.*
Noeton	10	59	45	51	*appr. (cun.)*
Holston Station	2	47	45	46	*cun.*
Austin Mill	3	54	45	48	*cun. (appr.)*
North Fork Holston River.					
Rotherwood	10	45	39	41	*cun.*
Hilton	8	43	36	40	*cun.*
Mendota	8	46	38	41	*cun.*

The general rule, from the Tennessee up the Holston, is seen.
Irregularities and more sudden changes (from the Tennessee to the
Holston, and from the latter to the North Fork) may be accounted
for, on the one hand, by scarcity of material, or, on the other, by the
sudden transition from a larger river to a smaller one.

  I leave out some material collected in tributaries of the Ten-
nessee and Holston, because it is fragmentary : but I should say
that it does not conflict with the rule. From the *Clinch River*, I
am able to offer the following table.

Loc.	No.	Max.	Min.	Av.	
Clinch River.					
Solway	1	55	55	55	*appr.*
Clinton	7	57	47	51	*appr. (cun.)*
Offutt	1	52	52	52	*appr.*
Black Fox Ford	3	45	40	43	*cun.*
Clinch River Station	6	45	40	43	*cun.*
Oakman	7	49	39	44	*cun.*
Horton Ford	1	39	39	39	*cun.*
Speers Ferry	9	42	36	40	*cun.*
Clinchport	6	44	38	41	*cun.*

The sudden change of obesity between Offutt and Black Fox
Ford undoubtedly is due to the fact that a long stretch of the river

intervenes from which no shells are at hand, and that above Offutt the Powell flows into the Clinch, the latter thus suddenly decreasing in size.

Material from the Powell is scanty, but it fits into the scheme. It is thus clear that also the *cuneolus*-group is subject to the law. It also holds good, as far as my material goes, in the Tennessee and its tributaries in northern Alabama, where this type of shells also seems to be abundant.

GROUP OF FUSCONAIA EDGARIANA IN THE UPPER TENNESSEE-SYSTEM.

I distinguish the following two forms, but use the specific name of *edgariana* (see *F. cor*, Ortmann, '18, pp. 532, 533).

1. FUSCONAIA EDGARIANA (Lea).—Dia. 50 per cent. or over.

Unio edgarianus Lea, '40 (Holston R., Tenn.; Tennessee R., Florence, Ala.).—*Pleurobema edgarianum* Simpson, '14, p. 741.

Dia. (Lea) : 64 per cent.; (Simpson) : 58, 69, 76 per cent.

Unio obuncus Lea, '71 (Tuscumbia, Ala.; Holston R., Tenn.).—Synonym to *edgarianum*, according to Simpson.

Dia. (Lea) : 53 per cent.

Unio andersonensis Lea. '72 (Holston R.; Clinch R., Anderson Co., Tenn.).—Synonym to *edgarianum*, according to Simpson.

Dia. (Lea) : 76 per cent.

2. FUSCONAIA EDGARIANA ANALOGA (Ortmann).—Dia. less than 50 per cent.

Fusconaia cor analoga Ortmann, '18, p. 533 (Clinch R., Speers Ferry).

My material from *Clinch River* has furnished the following figures.

Loc.	No.	Max.	Min.	Av.	
Clinch River.					
Edgemoor	1	58	58	58	*edgar.*
Needham Ford	2	51	42	46.5	*anal.* (*edgar.*)
Clinch River Station	2	48	47	47.5	*anal.*
Sneedville	1	49	49	49	*anal.*
Church Ford	1	42	42	42	*anal.*
Speers Ferry	8	49	43	46	*anal.*
Clinchport	6	45	41	43	*anal.*
St. Paul	7	45	40	43	*anal.*
Fink	2	48	41	45	*anal.*
Cleveland	6	44	40	42	*anal.*

The sudden jump between Edgemoor and Needham Ford is explained by the long distance between these two points.

In the *Powell River*, this shell is also found, and material is at hand from two places, Combs and Rose Hill. At the former place, the average diameter is 42 per cent., at the latter, 43 per cent. Here the lowest percentage has been found to be 38.

I did not collect shells of this type in the Holston below the forks, which is quite a remarkable fact. But the flat type turns up again in the North Fork, from Rotherwood to Holston P. O. Here the diameter lies between 41 and 48 per cent., and there is no apparent change in this comparatively short stretch of river.

Three shells from the *Tennessee* at Florence, Ala., have the dia. 55, 70, 70 per cent., with the average of 65, thus being more swollen than any shells from the upper Tennessee region. From a tributary some distance farther up, *Paint Rock River,* I have the following table.

Loc.	No.	Max.	Min.	Av.	
Paint Rock	10	54	47	51	*edgar. (anal.)*
Trenton	6	54	47	52	*edgar. (anal.)*
Princeton	1	49	49	49	*anal.*

This series may appear as unreliable, since the uppermost station contains only one shell; yet the fact is evident that the Paint-Rock-River-shells are less obese than those from the Tennessee below.

Although, on the whole, my material of the *edgariana*-group is somewhat fragmentary, the law is distinctly seen, chiefly in a portion of the Clinch River, from Needham Ford upwards, where conditions are typical. These are perfectly analogous to those observed in the *cuneolus*-group, and thus we are justified to distinguish also here two varieties, a swollen river form, and a flat headwaters-form, although the latter has not been named previously.

Group of Fusconaia barnesiana in the Upper Tennessee System.

I have treated of this group previously,[15] and have given an account of its taxonomy. Thus it suffices here to repeat only the

[15] *Nautil.,* 31, 1917, p. 58 ff.

general results, and to support them by tables of measurements. The material of this species is rather rich, and I shall not give the measurements of all of it, but shall restrict myself to selected examples which show the law clearly.

I have distinguished here three forms.

1. FUSCONAIA BARNESIANA (Lea).—Dia. 40–49 per cent.

2. FUSCONAIA BARNESIANA BIGBYENSIS (Lea).—Dia. less than 40 per cent.

3. FUSCONAIA BARNESIANA TUMESCENS (Lea).—Dia. 30 per cent. or over.

I first give the material from three large rivers in the vicinity of Knoxville.

Loc.	No.	Max.	Min.	Av.	
Tennessee River, Little R. Shoals.	1	57	57	57	*tum.*
Little Tenn. River, Monroe Co. ..	3	57	51	54	*tum.*
French Broad River, Boyd Creek.	5	55	45	50	*tum.* (*barn.*)

Holston River.

Mascot	1	48	48	48	*barn.*
Hodges	5	50	41	46	*barn.* (*tum.*)
Turley Mill	1	51	51	51	*tum.*
Noeton	5	52	45	49	*barn.* (*tum.*)
Holston Station	2	48	46	47	*barn.*
Austin Mill	1	40	40	40	*barn.*

South Fork Holston River.

Pactolus	3	45	42	43	*barn.*
Bluff City	8	42	36	39	*bigb.* (*barn.*)
Emmett	8	39	35	37	*bigb.*
Barron	1	34	34	34	*bigb.*

Middle Fork Holston River.

Chilhowie	3	37	35	36	*bigb.*

North Fork Holston River (next station below, Austin Mill, has av. 40 per cent. = *barn.*).

Loc.	No.	Max.	Min.	Av.	
Rotherwood	8	43	38	40	*barn.* (*bigb.*)
Mendota	4	41	36	39	*bigb.* (*barn.*)
Holston P. O.	5	40	35	37	*bigb.* (*barn.*)
Saltville	7	39	34	37	*bigb.*

Big Mocasin Creek (next station below, Rotherwood, has av. 40 per cent.).

Loc.	No.	Max.	Min.	Av.	
Moccasin Gap	10	40	32	37	*bigb.* (*barn.*)
Willow Springs	2	38	35	36.5	*bigb.*

It hardly needs to be pointed out that, beginning in the large rivers, *tumescens* passes gradually into *barnesiana*, and farther up, into *bigbyensis*. This is one of the best and most convincing series.

In *Clinch River*, conditions are similar, but the only specimen from the lowermost station (Solway) makes an exception, but a rather striking one. We may however, very well disregard it, and take it simply for an abnormal case. With the next station above it (Edgemoor), the normal condition is seen to begin.

Loc.	No.	Max.	Min.	Av.	
Clinch River.					
Solway	1	38	38	38	*bigb.*
Edgemoor	4	52	49	50	*tum.* (*barn.*)
Clinton	1	45	45	45	*barn.*
Walker Ford	2	49	46	47.5	*barn.*
Kyle Ford	1	41	41	41	*barn.*
Clinchport	1	36	36	36	*bigb.*
St. Paul	1	35	35	35	*bigb.*
Fink	1	38	38	38	*bigb.*
Raven	6	38	32	36	*bigb.*
Richland	12	40	33	36	*bigb.* (*barn.*)
Cedar Bluff	10	39	32	36	*bigb.*
Tazewell	1	39	39	39	*bigb.*

Powell River (next station below is Clinton, with 45 per cent. = barn.).

Loc.	No.	Max.	Min.	Av.	
Greens Ford	2	40	40	40	*barn.*
Combs	4	37	36	37	*bigb.*
Rose Hill	1	37	37	37	*bigb.*
Dryden	7	41	36	39	*bigb.* (*barn.*)
Big Stone Gap	12	41	31	36	*bigb.* (*barn.*)

No comment is necessary, except that it should be noted that, in this species, the intermediate form (*barnesiana*) turns up, occasionally, way up in the headwaters. This, of course, is due to the fact that the limits drawn between the three forms are very narrow.

In some of the tributaries of the upper Tennessee, *tumescens*, according to my material, passes only into *barnesiana*, without the most compressed form of *bigbyensis* being well represented. This is seen, for instance, in *Little Pigeon River* at Sevierville, a tributary to the *French Broad*. The latter, at Boyd Creek possesses *tumescens* with the average diameter of 50 per cent., with an ad-

mixture of some specimens of *barnesiana*. From Sevierville, I have
ten specimens, ranging from 45 to 38 per cent., the average being
42 per cent., thus representing *barnesiana* with an interspersing of a
few *bigbyensis*. I have no doubt, however, that, if there was any
material from farther up stream, pure *bigbyensis* would appear.

Finally, the same conditions obtain in the Tennessee drainage in
northern Alabama. In the *Tennessee River* at Florence is a form
(12 specimens measured) in which the diameter ranges from 64 to
50 per cent., with the average at 56 per cent. This is pure *tumes-
cens*. In the tributaries we find mostly the more compressed forms
of the *barnesiana*- and *bigbyensis*-type, so, for instance, in *Elk
River*, at Fayetteville (1 specimen), a form with the diameter of
44 per cent. (*barnesiana*), and farther up, at Estill Springs (8
specimens), a form ranging from 40 to 35 per cent., with the average
of 38 per cent., which corresponds to *bigbyensis*.

Thus the contention is substantiated, that *tumescens* of the large
rivers passes through *barnesiana* into *bigbyensis* of the headwaters.

Group of Amblema peruviana (Lamarck).

The extremes of this group of forms are marked by *Amblema
peruviana* (Lam.) (= *Quadrula plicata* Simpson, '14, p. 814) and
Amblema costata (Raf.) (= *Quadrula undulata* (Barn.) Simpson,
p. 819). But there are other described " species" which fall into
this group.

Wilson and Clark (1914) and Utterback (1916) have referred to
these as showing the same phenomenon of a swollen form inhabit-
ing the large rivers, and a flat one in the smaller streams (Cumber-
land and Osage River systems). I have no doubt that this is
correct, and that it applies also to other rivers.

According to my experience, there is no question that specimens
of *A. costata* in the Ohio River below Pittsburgh are more obese
than the greatly compressed specimens found, for instance, in the
Beaver and upper Allegheny drainages. However, I do not possess
sufficient material from the middle and lower Ohio, to show the
actual transition into *peruviana*. Also in the Tennessee-system, I
did not go far enough down to reach the range of the latter: what I

have found in the Knoxville region, and what I have from the Tennessee in northern Alabama, should all be classed with *A. costata*.

QUADRULA PUSTULOSA (Lea) (Simpson, '14, p. 848).

This is a species which generally avoids smaller streams, both in the Ohio and upper Tennessee drainages. Consequently, not much difference is observed in obesity. Nevertheless a slight indication of our law is seen in so far, as the most compressed individuals come from the most extreme stations in the upstream direction.

Generally speaking, in the Ohio and Tennessee systems, this species has a diameter between 50 and 70 per cent. Specimens falling under 50 per cent. are at hand from the following localities.

Licking Riv., Farmer.—Four specimens, dia. 47–45 per cent., average: 46 per cent.

Big Sandy Riv., Prestonsburg.—One among three specimens has the dia. of 44 per cent., the others have 50 and 52 per cent.

Pocatalico Riv., Raymond City.—Two specimens, dia. 48 and 45 per cent.

Little Kanawha Riv., Burnsville.—One specimen with 46 per cent. (another with 50 per cent.).

Allegheny Riv., Kelly.—One specimen with 49 per cent. among others more obese.

Cheat Riv., Cheat Haven.—One specimen with 48 per cent., and two others more obese.

All these stations are well upstream, and in no case, this species has been found above these points. Thus it is seen, that unusually flattened individuals turn up only in smaller streams or at the uppermost limit of the distribution. In the Tennessee system, no specimens under 50 per cent in diameter have been found.

QUADRULA METANEVRA (Rafinesque), and var. WARDI (Lea).
Simpson, '14, pp. 834, 835.

The form *wardi* has been separated from typical *metanevra* because of its greater compression and greater smoothness, the large knobs, so characteristic for the main species, being absent or very slightly developed.

The true *metancvra* is restricted mainly to larger rivers. But occasionally it goes into smaller rivers, but hardly ever into the headwaters. It has been reported repeatedly from rather small streams, but then it was generally represented by the var. *wardi*. The original localities of the latter are *Walhonding River*, Ohio (tributary to Tuscarawas) ; *Wapsipinicon River* (Wassepinicon), Iowa ; and *Coal River*, Logan Co., Va. (Coal River is now in Kanawha and Boone Cos., W. Va.). Three specimens from the latter locality were in the Hartman collection, and are now in the Carnegie Museum.

Sterki[16] reports *wardi* from *Sugar Creek,* another tributary of Tuscarawas River.

Aside from the types of *wardi* from Coal River, the Carnegie Museum possesses this form from the Ohio, Monongahela and Allegheny Rivers in the vicinity of Pittsburgh. But these specimens are not very typical, are rare, and intergrade with the normal *metancvra*. They are found, however, at and near the upstream limit of the distribution of the species. A rather good specimen of *wardi* comes from the *Little Kanawha River* at Burnsville. This again is a smaller stream.

Thus the tendency is observed, when the species enters smaller streams, to develop a compressed variety. But, in addition, this variety inclines to obliterate a peculiar sculpture, very characteristic for the main species, that of large knobs upon the surface of the shell. This should be kept in mind.

QUADRULA CYLINDRICA (Say). Simpson, '14, p. 832.

This widely distributed species ordinarily is strongly nodulous, with great knobs upon the posterior ridge, and the shell is generally much swollen. Its characters are rather uniform over the range.

However in the headwaters of the Ohio River, in Ohio and Pennsylvania, and in the upper Tennessee-region, two peculiar small-stream-races have developed. In the *Tuscarawas River,* in *Beaver River,* and *French Creek,* there is a remarkably compressed form, which, in addition, is practically smooth, having lost not only the

[16] *Proc. Ohio Acad. Sci.,* 4, 1907.

large knobs, but also the nodules.[17] It hardly, however, forms a distinct race here, being rare, and passing insensibly into the normal type.

In the *upper Tennessee;* there is an analogous form, also greatly compressed, and without the large knobs. It is, however, not smooth, but thickly covered with small nodules, even more so than the normal form. It has been called var. *strigillata* (Wright). Simpson (l. c.) does not accept this, because there is an "absolute graduation" to this form. Yet in the *upper Clinch,* from the Tennessee-Virginia state line upward, this variety becomes a pure race, which is very striking. It is also in Powell River and the North Fork Holston, but not so well developed.

In this instance, it is clearly seen that analogous, compressed forms are being developed independently in the upper Ohio and the upper Tennessee systems, and their independence is shown by the difference in the character of the nodules: the one is practically smooth, the other strongly nodulous. But in the disappearance of the large knobs they agree again.

I shall give here the measurements of the form in the *Clinch River.* In the last column, in this case, the name given refers to the development of the large knobs.

Loc.	No.	Max.	Min.	Av.	
Edgemoor	3	35	34	35	*cyl.*
Clinton	2	41	31	39	*cyl.*
Clinch River Station	6	39	34	36	*cyl.*
Speers Ferry	2	38	34	36	*cyl.*
Clinchport	5	35	32	33	*cyl. (strig.)*
Fink	1	31	31	31	*cyl.-strig.*
Cleveland	6	35	28	31	*strig.*
Raven	2	30	30	30	*strig.*
Richland	4	31	28	30	*strig.*
Cedar Bluff	1	27	27	27	*strig.*

ROTUNDARIA TUBERCULATA (Rafinesque), and R. GRANIFERA (Lea).

Quadrula tub. and gran. Simpson, '14, pp. 903, 905.

According to Wilson and Clark,[18] these two forms show, in the Cumberland River, the phenomenon that the swollen form (*grani-*

[17] Sterki, *Pr. Ohio Ac.,* 4, '07, p. 390, mentions this form first.

[18] L. c., '14, p. 63.

fera) of the lower parts of the river passes gradually into the more compressed form (*tuberculata*) of the headwaters. I have not sufficient material to substantiate this by measurements, since all my material, from the middle Ohio upwards, and from the upper Tennessee, clearly belongs to the compressed *tuberculata*-type. But the general rule, at least, is thus confirmed, that the swollen form, *granifera*, is not found in the upper course of these rivers.

GROUP OF LEXINGTONIA DOLABELLOIDES IN THE UPPER TENNESSEE-SYSTEM.

The *dolabelloides*-group is common in the upper Tennessee, and also in the Tennessee-drainage in Alabama, and I again distinguish a swollen and a compressed form, the first in the larger rivers, the second in the headwaters. They pass gradually into each other, and the line drawn between them, at the diameter of 50 per cent., again is artificial. The nomenclature and synonymy is as follows:[19]

1. LEXINGTON DOLABELLOIDES (Lea).—Dia. 50 per cent. or over.

Unio dolabelloides Lea, '40 (Holston R., Tenn.).—*Pleurobema dol.* Simpson, '14, p. 752.

Dia. (Lea) : 63 per cent.; (Simpson) : 67 and 71 per cent.

Unio thorntoni Lea, '57 (Tuscumbia, Ala.).—Recognized as synonym by Simpson.

Dia. (Lea) : 66 per cent.

Unio mooresianus Lea, '57 (Tuscumbia, Ala.).—Synonym, according to Simpson.

Dia. (Lea) : 67 per cent.

Unio recurvatus Lea, '71 (Tennessee R.; Holston R.).—Synonym, according to Simpson.

Dia. (Lea) : 63 per cent.

Uino circumactus Lea, '71 (Florence, Ala.; Holston R., Tenn.).— Synonym, according to Simpson.

Dia. (Lea) : 58 per cent.

Unio subglobatus Lea, '71 (Florence, Ala.; Nashville, Tenn.).— Synonym, according to Simpson.

Dia. (Lea) : 73 per cent.

[19] See Ortmann, *Proc. Amer. Philos. Soc.,* 57, '18, pp. 545, 546.

2. LEXINGTONIA DOLABELLOIDES CONRADI (Vanatta).—Dia. less than 50 per cent.

Unio maculatus Conrad, '84 (Elk and Flint R., Ala.).—*Pleurobema maculatum* Simpson, '14, p. 737.

Dia. (Simpson) : 46 per cent.

Pleurobema appressum Simpson, '14, p. 747 (Tuscumbia, Ala.; Tennessee and Holston R., Tnnn.).

Dia. 47 per cent.

I submit here the following tables:

Loc.	No.	Max.	Min.	Av.	
Tennessee River.					
Florence	4	71	62	67	*dolab.*
Bridgeport	5	68	54	60	*dolab.*
Rathburn	1	74	74	74	*dolab.*
French Broad River, Boyd Creek.	2	61	59	60	*dolab.*
Clinch River.					
Solway	1	50	50	50	*dolab.*
Clinton	4	54	49	52	*dolab. (conr.)*
Agee	1	50	50	50	*dolab.*
Clinch River Station	1	44	44	44	*conr.*
Clinchport	1	42	42	42	*conr.*
St. Paul	1	45	45	45	*conr.*
Cleveland	5	40	39	40	*conr.*
Raven	6	39	34	36	*conr.*
Richland	2	38	36	37	*conr.*
Cedar Bluff	2	37	36	36.5	*conr.*

Similar conditions prevail in *Powell River,* where no *dolabelloides* have been met with, and where the percentage of *conradi* drops to 37 at Big Stone Gap.

Remarkably enough, I did not find this shell in the *Holston* proper (a case parallel to that of *Fusconaia edgariana*), but it is present again, in the shape of *conradi,* in *North* and *South Fork Holston,* and again the law is evident here. This is shown in the following table.

Loc.	No.	Max.	Min.	Av.	
South Fork Holston River.					
Bluff City	4	43	40	41	*conr.*
Emmett	1	42	42	42	*conr.*
Fish Dam	1	37	37	37	*conr.*

North Fork Holston River.

Rotherwood	1	40	40	40	*conr.*
Hilton	2	42	41	41.5	*conr.*
Mendota	8	45	36	40	*conr.*
Saltville	8	40	36	37	*conr.*

Finally, I am able to tabulate the conditions in *Paint Rock River* in Alabama. It should be remembered that, in the main river in this region, *dolabelloides* is present with the average dia. of 67 and 60 per cent., and the minimum of 54 per cent.

Loc.	No.	Max.	Min.	Av.	
New Hope	10	64	49	57	*dolab.* (*conr.*)
Paint Rock	10	57	38	45	*conr.* (*dolab.*)
Princeton	7	44	38	40	*conr.*

This last series completely connects the two forms, which connection was not so evident in the lower Clinch on account of the scarcity of material.

Group of Pleurobema cordatum in the Upper Ohio-drainage.

This is an extremely difficult and polymorphous group on account of the complexity of conditions and the variability of other characters of the shell, besides obesity. I have indicated, in a general way, the main phases of this species.[20] But most of them may be dismissed for our present purposes. Yet there are two of them, *Pl. cordatum catillus* and *Pl. cordatum coccineum,* which clearly submit to the law, as will be demonstrated in the tables.

The synonymy of these forms is as follows (It should be noted that I call the main species *cordatus* (Rafinesque), and not *obliquum* (Lamarck): the reason for so doing will be given elsewhere).

1. Pleurobema cordatum catillus (Conrad).—Dia. 50 per cent. or over.

Unio catillus Conrad, '36 (Scioto R., Ohio).

Dia. (Conrad) : 51 per cent.

Unio solidus Lea, '38 (Ohio R., Cincinnati; Mahoning R., Ohio).— Quadrula solida Simpson, '14, p. 885.

Dia. (Lea) : 60 per cent. Of the four specimens measured by Simpson, only two belong here with the Dia. 58 and 59 per cent.

[20] Ortmann, '18, p. 547 ff.

Unio coccineus Lea, '38 (Ohio R., Marietta; Mahoning R., Ohio; Columbus, Ohio).

Dia.: 53 per cent.

Unio fulgidus Lea, '45 (Alexandria, La., probably a mistake).

Dia.: 60 per cent.

2. PLEUROBEMA CORDATUM COCCINEUM (Conrad).—Dia. less than 50 per cent.

Unio coccineus Conrad, '36 (Mahoning R., near Pittsburgh).— *Quadrula coccinea* Simpson, '14, p. 883.

Dia. (Conrad): 37 per cent.; (Simpson): 43, 46 per cent.

Loc.	No.	Max.	Min.	Av.	
Ohio River.					
Portsmouth	2	67	56	61.5	*cat.*
Portland	3	64	55	60	*cat.*
St. Mary's	4	67	59	63	*cat.*
Toronto	6	62	54	58	*cat.*
Cooks Ferry	14	65	50	57	*cat.*
Industry	16	64	52	57	*cat.*
Coraopolis	1	51	51	51	*cat.*
Allegheny River.					
Natrona	1	56	56	56	*cat.*
Aladdin	5	56	53	54	*cat.*
Godfrey	22	63	41	54	*cat.* (*cocc.*)
Johnetta	1	55	55	55	*cat.*
Kelly	67	62	40	51	*cat.* (*cocc.*)
Templeton	3	53	49	51	*cat.* (*cocc.*)
Walnut Bend	1	56	56	56	*cat.*
Tionesta	1	47	47	47	*cocc.*
Hickory	3	54	45	49	*cocc.* (*cat.*)
Warren	2	54	49	51.5	*cat.* (*cocc.*)
Larabee	12	51	44	47	*cocc.* (*cat.*)

Thus *catillus* does not entirely disappear in the headwaters of the Allegheny River. This is different in *French Creek*, which goes into the Allegheny above the station of Templeton in the last table, where the average diameter is 51 per cent.

Loc.	No.	Max.	Min.	Av.	
French Creek (follows Templeton).					
Utica	3	52	35	43	*cocc.* (*cat.*)
Cambridge Springs	6	45	37	42	*cocc.*
Conneauttee Creek, Edinboro	1	41	41	41	*cocc.*
Leboeuf Creek, Waterford	3	43	38	40	*cocc.*

I have also a very interesting series from the *Beaver drainage*. Just below the mouth of Beaver River, in the Ohio at Industry, pure *catillus* is present with the average diameter of 57 per cent.

Loc.	No.	Max.	Min.	Av.	
Beaver River.					
Wampum	14	61	48	53	*cat. (cocc.)*
Mahoning River.					
Mahoningtown	3	53	46	50	*cat. (cocc.)*
Coverts	1	50	50	50	*cat.*
Leavittsburgh	3	49	46	47	*cocc.*
Newton Falls	1	41	41	41	*cocc.*
Shenango River (follows Wampum).					
Harbor Bridge	3	48	43	46	*cocc.*
Pulaski	5	45	41	43	*cocc.*
Sharpsville	1	43	43	43	*cocc.*
Clarksville	9	52	41	47	*cocc. (cat.)*
Shenango	5	49	42	46	*cocc.*
Jamestown	17	48	37	43	*cocc.*

The elevation of the diameter at Clarksville is due to the presence of a number of quite young specimens. We have learned, under the group of *Fusconaia subrotunda,* that the diameter of young shells is comparatively greater. Older individuals at this locality are all pure *coccineum*.

Even in a small creek like the *Neshannock,* the law becomes visible.

Loc.	No.	Max.	Min.	Av.	
Eastbrook	8	43	36	40	*cocc.*
Neshannock Falls	3	48	35	41	*cocc.*
Volant	4	42	39	40	*cocc.*
Leesburg	4	40	36	38	*cocc.*

Similar conditions prevail in the *Monongahela drainage*. At Charleroi, the form *catillus* is rather pure. From farther up I have only scanty material, but at the mouth of *Cheat River,* at Cheat Haven, *catillus* is present (diameter about 50 per cent. or slightly more). From the West Fork River I have only specimens of typical *coccineum,* all with the diameter below 50 per cent.

Group of Pleurobema oviforme in the Upper Tenessee-drainage.

Great confusion has prevailed hitherto with regard to the shells belonging here. In a previous paper I have tried to bring order into this group,[21] and have divided it into three subspecies, because

[21] Pr. Amer. Philos. Soc., 57, '18, p. 550 ff.

the oldest name given was applied to a form intergrading between the extremes. The synonymy is as follows.

1. Pleurobema oviforme (Conrad).—Dia. 40 to 49 per cent. of length.

Unio oviformis Conrad, '34 (Tennessee).—*Pleurobema oviforme* Simpson, '14, p. 745.

Dia. (Simpson) : 43 per cent.

Unio ravenelianus Lea, '34 (French Broad R., Asheville, N. Car.) —*Pleurobema rav.* Simpson, '14, p. 796.

Dia. (Lea) : 43 per cent.; (Simpson) : 40 and 43 per cent. Another specimen measured by the latter has 50 per cent.

Unio lesleyi Lea, '60 (Kentucky, Tennessee).—*Pleurobema lesl.* Simpson, '14, p. 744.

Dia. (Lea) : 43 per cent. Specimens measured by Simpson give 31 and 39 per cent., and, consequently, do not belong here.

Unio ornatus Lea, '61 (Alabama).—*Pleurobema orn.* Simpson, '14, p. 746.

Dia. (Lea) : 43 per cent. ; (Simpson, supposed type) : 44 per cent.

Unio clinchensis Lea, '67 (Clinch, French Broad, Holston).—*Pleurobema clinch.* Simpson, '14, p. 743.

Dia. (Lea and Simpson) : 44 per cent.

Unio conasaugaënsis Lea, '72 (Conasauga Cr., Monroe Co., Tenn.), —*Pleurobema con.* Simpson, '14, p. 800.

Dia. (Lea) : 45 per cent.; (Simpson) : 40 per cent.

2. Pleurobema oviforme argenteum (Lea).—Dia. less than 40 per cent.

Unio argenteus Lea, '41 (Holston R., Tenn.).—*Pleurobema arg.* Simpson, '14, p. 798.

Dia. (Lea) : 38 per cent.; (Simpson) : 32 per cent.

Unio striatissimus Anthony, '65 (Tennessee).
 Dia. 30 per cent.

Unio planior Lea, '68 (Tennessee; Holston R., Washington Co., Va.).—*Pleurobema planius* Simpson, '14, p. 302.
 Dia. (Lea) : 35 per cent.; (Simpson) : 33 per cent.

Unio brevis Lea, '72 (Conasauga Cr., Monroe Co., Tenn.).—*Pleuro-bema breve* Simpson, '14, p. 800.
 Dia. (Lea) : 35 per cent.; (Simpson) : 36 per cent.

Unio swordianus Wright, '97 (Powell R., Lee Co., Va.).—*Pleuro-bema sword.* Simpson, '14, p. 757.

Dia. (Simpson) : 40 per cent. These measurements are taken from an extremely obese specimen. Other specimens in the original lot all fall below 40 per cent.

 3. PLEUROBEMA OVIFORME HOLSTONENSE (Lea).—Dia. 50 per cent. or over.

Unio holstonensis Lea, '40 (Holston R.).—*Pleurobema holst.* Simpson, '14, p. 739.
 Dia. (Lea) : 54 per cent.; Simpson) : 50, 56, 58 per cent.

Unio mundus Lea, '57 (Tennessee R., Ala.).—Synonym to *holston-ense,* according to Simpson.
 Dia. (Lea) : 64 per cent.

Unio tesserulæ Lea, '61 (Nolichucky R., Tenn.).—*Pleurobema tess.* Simpson, '14, p. 749.
 Dia. (Lea and Simpson) : 64 per cent.

Unio pattinoides Lea, '71 (Clinch and Holston).—Synonym to *holstonense,* according to Simpson.
 Dia. (Lea) : 51 per cent.

Unio acuens Lea, '71 (Tennessee R., Concord, Tenn.).—*Pleuro-bema acuens* Simpson, '14, p. 746.
 Dia. (Lea) : 55 per cent. Simpson's measurements give 48 per cent., and thus belong to typical *oviforme.*

Unio lawi Lea, '71 (Tennessee R., Tuscumbia, Ala., Holston R.).—Synonym to *holstonense,* according to Simpson.
 Dia. (Lea) : 56 per cent.

Unio bellulus Lea, '72 (Holston R.; Tennessee R., Mussel Shoals, Ala.).—Synonym to *holstonense,* according to Simpson.
 Dia. (Lea) : 64 per cent.

TABLE OF THE FORMS OF THE OVIFORME-GROUP.

Loc.	No.	Max.	Min.	Av.	
Tennessee River.					
Florence	1	55	55	55	*holst.*
Rathburn	2	57	56	56.5	*holst.*
Chota Shoals	2	54	54	54	*holst.*
Little River Shoals	2	51	46	48.5	*ovif.* (*holst.*)
Holston River.					
Mascot	2	51	48	49.5	*ovif.* (*holst.*)
Hodges	6	48	44	46	*ovif.*
Turley Mill	1	41	41	41	*ovif.*
Noeton	1	47	47	47	*ovif.*
Holston Station	1	44	44	44	*ovif.*
South Fork Holston River.					
Pactolus	3	46	38	42	*ovif.* (*argent.*)
Bluff City	6	38	35	37	*argent.*
Emmett	10	43	32	36	*argent.* (*ovif.*)
Barron	1	38	38	38	*argent.*
Middle Fork Holston River.					
Chilhowie	8	38	31	35	*argent.*

Watauga River (just below, at Pactolus, there is *oviforme* (*argenteum,* av. 42 per cent.).

Loc.	No.	Max.	Min.	Av.	
Watauga	8	39	33	36	*argent.*

North Fork Holston River (at Holson Station is *oviforme,* 44 per cent.).

Loc.	No.	Max.	Min.	Av.	
Rotherwood	10	46	29	38	*argent.* (*ovif.*)
Hilton	8	44	32	38	*argent.* (*ovif.*)
Mendota	10	45	34	39	*argent.* (*ovif.*)
Saltville	10	38	32	35	*argent.*

Big Mocasin Creek (above Rotherwood).

Loc.	No.	Max.	Min.	Av.	
Mocassin Gap	12	39	33	35	*argent.*
Willow Springs	5	39	30	34	*argent.*
Clinch River.					
Edgemoor	1	53	53	53	*holst.*
Clinton	2	45	44	44.5	*ovif.*
Kyle Ford	3	47	38	42	*ovif.* (*argent.*)
Speers Ferry	2	38	36	37	*argent.*
Clinchport	5	47	42	44	*ovif.*
St. Paul	4	38	35	37	*argent.*
Fink	2	39	34	37	*argent.*
Cleveland	10	47	36	40	*ovif.* (*argent.*)
Raven	5	43	36	39	*argent.* (*ovif.*)
Richland	8	41	34	36	*argent.* (*ovif.*)
Cedar Bluff	12	43	33	37	*argent.* (*ovif.*)

There are some irregularities in the Clinch, which may be explained by insufficient matrial. The form *oviforme* goes up to the uppermost locality, but it becomes rare in the headwaters; and further, it may give way entirely to *argenteum* above Cedar Bluff. The decease of obesity is noted chiefly in the minima.

In *Powell River, oviforme* alone or associated with *argenteum* goes up to Olinger. However, at Big Stone Gap, among 9 specimens, the max. was 38 per cent., the min. 31 per cent., and the av. 35 per cent.: pure *argenteum*.

The same law is observed in other tributaries of the Tennessee system in East Tennessee. In *French Broad River* at Boyd Creek, *oviforme* prevails, with occasional *holstonense*. In the mountains at Asheville, the average diameter was found to be 44 per cent. (*oviforme*), with occasional *argenteum* among them. I have examined 6 specimens in the Walker collection, labeled *ravenelianum*, with the max. of 49 per cent. and the min. of 38 per cent. A very similar form I collected in *Hiwassee River* at Austral; in 8 specimens the max. was 52 per cent., the min. 43 per cent., and the av. 48 per cent.: these represent *oviforme* with occasional *holstonense*.

Also in northern Alabama and the adjoining parts of Tennessee I have found evidence for our law, as is shown by the following instances.

Loc.	No.	Max.	Min.	Av.	
Paint Rock River.					
Paint Rock	2	55	50	52.5	*holst.*
Trenton	2	41	41	41	*ovif.*
Princeton	5	47	39	42	*ovif.* (*argent.*)
Elk River.					
Fayetteville	1	44	44	44	*ovif.*
Estill Springs	8	41	33	36	*argent.* (*ovif.*)
Boiling River, Cowan	4	42	36	38	*argent.* (*ovif.*)

The last two localities are about equivalent as to their situation.

GROUP OF PLEUROBEMA CLAVA.

Pleurobema clava is absent in the upper Tennessee-region. It turns up, however, in the Tennessee drainage in northern Alabama. Yet my material is too scanty to form an opinion as to the interrelation of this form with *oviforme*. *Pl. clava* is abundant in the upper

Ohio system, and on account of its close affinity to *Pl. oviforme,* we might expect to find our law expressed. But the fact is that in this region no large-river-type is present, *Pl. clava* avoiding larger streams. Measurements of the material at hand have furnished no evidence for a change of obesity correlated with station. The measurements correspond roughly to those of the typical *oviforme* (between 40 and 50 per cent.), and there is also no form parallel to *argenteum.*

I also have investigated material from the Coosa River in Georgia and Alabama belonging to *Pleurobema decisum* (Lea) and *Pl. chattanoogaënse* (Lea). These two species undoubtedly represent the *clava*-group and the typical *oviforme.* Very slight evidence was found of a change of obesity according to station, yet some indications of it were present. The lowest figures for the average diameter were obtained in specimens from *Conasauga River* in Whitfield Co., Ga.; the highest figures in the lower reaches of *Coosa River* in Chilton and Elmore Cos., Ala. Yet the differences are slight at the best (max. 55, min. 38 per cent.), and the irregularities are many. Also the material is very unequal as regards the number of specimens measured from one and the same locality. Thus I pass over these forms, only calling attention to the posibility that the existence of the same law might be demonstrated also in these cases.

DROMUS DROMAS (Lea) and DR. DROMAS CAPERATUS (Lea).
Simpson, '14, pp. 341, 343.

Wilson and Clark ('14, pp. 54, 63) have first pointed out that, in the Cumberland River, these two forms run together, and that the flattened *caperatus* is in the headwaters, and the swollen *dromas* in the main river (see also Ortmann, '18, p. 566).

In this species, conditions are somewhat complicated by the fact that the swollen form has also a peculiar " hump," or large tubercle, upon each valve, which becomes more or less obliterated in the flat form, being often entirely missing. Thus it is rather hard to draw a line. We may assume, that *D. dromas* is the swollen type, with the diameter of 50 per cent. or over, and a well-developed hump;

while *D. dromas caperatus* is the compressed form, with the diameter less than 50 per cent., and without hump. But we must bear in mind that some moderately swollen individuals have no hump; and that, more frequently, flat specimens may have more or less distinct traces of this hump.

The original measurements taken from Lea, Conrad, and Simpson, give for the *typical* form a diameter ranging from 50 to 84 per cent., while the diameter of *caperatus* ranges from 42 to 48 per cent.

I am able to submit the following table.

Loc.	No.	Max.	Min.	Av.	
Tennessee River.					
Tuscumbia	4	74	59	66	*drom.*
Konxville	1	58	58	58	*drom.*
Holston River.					
McMillan	2	56	53	54.5	*drom.*
Mascot	10	61	43	52	*drom. (cap.)*
Hodges	3	58	50	55	*drom.*
Turley Mill	3	63	52	56	*drom.*
Noeton	1	48	48	48	*cap.*
Holston Station	3	56	47	52	*drom. (cap.)*

Farther up in the Holston, this species has not been found. It is clear that the form *caperatus* is not well developed here, and this is also shown by the fact that traces of the hump are found to the uppermost station, although, on the other hand, already one of the specimens at McMillan is without any hump. In the *Clinch* and *Powell,* conditions are more favorable to the development of the *caperatus*-type, as is seen in the next table.

Loc.	No.	Max.	Min.	Av.	
Clinch River.					
Solway	2	53	49	51	*drom. (cap.)*
Edgemoor	16	58	41	49	*cap. (drom.)*
Clinton	6	52	43	47	*cap. (drom.)*
Offutt	5	51	40	46	*cap. (drom.)*
Clinch River Station	1	46	46	46	*cap.*
Powell River.					
Combs	1	46	46	46	*cap.*
Arthur	1	42	42	42	*cap.*

Combs is about equivalent to Clinch River Station. Also here the development of the hump is variable, but specimens without it

prevail at the upper stations. The metropolis of *caperatus* is clearly in Clinch and Powell Rivers, toward the headwaters. It should be noticed that this species does not go very far up in the rivers, and that it is by no means a small-creek-form.

Group of Obovaria subrotunda in the Upper Ohio-drainage.

The synonymy of these forms is as follows (see Ortmann, '18, p. 567, 568, but the name *lens* has been restored for *levigata*).

1. Obovaria subrotunda (Rafinesque).—Dia. 60 per cent. or over.

Obliquaria subrotunda Rafinesque, '20 (Ohio).—*Obovaria subrotunda* Vanatta, '15, p. 552.

Dia. (Vanatta): 72 per cent.

Unio circulus Lea, '29 (Ohio R., Cincinnati; Monongahela R., Pittsburgh).—*Obovaria circ.* Simpson, '14, p. 291.

Dia. (Lea): 73 per cent.; (Simpson): 58, 67, 72 per cent. (the first given by Simpson falls under the variety!).

2. *Obovaria subrotunda lens* (Lea).—Dia. less than 60 per cent.

Unio lens Lea, '31 (Ohio and Tennessee).—*Obovaria lens* Simpson, '14, p. 293.

Dia. (Lea): 48 per cent.; (Simpson): 52 per cent.

The material from the *upper Ohio system* shows that these two forms intergrade completely, as I have pointed out already in 1909, and *subrotunda* is the large-river-form, while *lens* is found toward the headwaters.

Loc.	No.	Max.	Min.	Av.	
Ohio River.					
Portland	12	66	53	62	*subr. (lens)*
Parkersburg	2	62	59	60.5	*subr. (lens)*
St. Mary's	7	67	51	62	*subr. (lens)*
Coraopolis	5	64	57	61	*subr. (lens)*
Monongahela River.					
Charleroi	5	68	53	60	*subr. (lens)*
West Fork River.					
Lynch Mines	4	56	50	53	*lens*
Lightburn	3	49	48	49	*lens*
Weston	2	49	45	47	*lens*

Allegheny River.

Natrona	1	52	52	52	*lens*
Godfrey	1	51	51	51	*lens*

Crooked Creek.

Rosston	12	59	48	52	*lens*
Creekside	5	51	48	50	*lens*

The sudden decrease of obesity from the Monongahela to West Fork River is clearly due to the absence of material from a long stretch in the Monongahela. Also in the Allegheny the change is rather abrupt, due to scarcity of material. The gradual transition of the two forms is, however, quite evident in the *Beaver-drainage.*

	Loc.	No.	Max.	Min.	Av.
Beaver River.					
Wampum	14	64	49	53	*lens (subr.)*
Shenango River.					
Harbor Bridge	3	56	50	53	*lens*
Pulaski	2	58	49	53.5	*lens*
Clarksville	7	54	48	51	*lens*

Also in *Elk River* in West Virginia this is seen.

	Loc.	No.	Max.	Min.	Av.
Elk River.					
Shelton	1	67	67	67	*subr.*
Clay	2	62	60	61	*subr.*
Gassaway	7	70	56	61	*subr. (lens)*
Sutton	9	65	53	58	*lens (subr.)*

Some material from the *Little Kanawha* also fits into the scheme, but it should be pointed out that the locality on Hughes River, although not quite so far upstream as the others, surely is in the smaller stream.

	Loc.	No.	Max.	Min.	Av.
Little Kanawha River.					
Grantsville	2	68	59	63.5	*subr. (lens)*
Burnsville	5	59	50	53	*lens*
North Fork Hughes River.					
Cornwallis	1	50	50	50	*lens*

GROUP OF OBOVARIA SUBROTUNDA IN THE UPPER TENNESSEE.

In the uppermost Tennessee drainage, *Obovaria subrotunda* is extremely rare; above Knoxville, it does not go anywhere into the

smaller streams, and I have only a few specimens from the lower Clinch and the lower Holston. These shells are *O. subrotunda*, associated with *lens* of moderate obesity (max. 62 per cent., min. 55 per cent.).

In a tributary of the Tennessee in Alabama, the law again becomes visible. Material from *Paint Rock River* has been examined: although only the form *lens* is represented, it shows distinctly a decrease of the obesity in the upstream direction, and at the lowermost station specimens are found which are very close to *subrotunda*.

Loc.	No.	Max.	Min.	Av.	
Paint Rock River.					
Paint Rock	14	59	46	54	*lens*
Trenton	12	53	46	49.6	*lens*
Holly Tree	1	48	48	48	*lens*
Princeton	12	52	43	49.3	*lens*

The irregularity at Holly Tree, of course, is due to scarcity of material.

These are the instances I am able to offer, at the present time, for the phenomenon that a species changes its obesity along the course of a river or rivers. I am quite sure that, in the upper Ohio and upper Tennessee drainages, there are hardly any other instances of this kind, for I am very familiar with these faunas. There is only one additional species both in the Ohio and Tennessee drainages, *Lampsilis ovata* (Say), which develops a variety, *L. ovata ventricosa* (Barnes), which prevails towards the headwaters, and is exclusively found in certain smaller creeks. These forms, however, do not so much differ in obesity, but in other characters (development of posterior ridge and truncation of posterior slope).

Also possibly some species of *Truncilla* might show the same changes in obesity (*Truncilla torulosa* (Raf.), turning, in the upper Ohio into *Tr. rangiana* (Lea), and in the upper Tennessee into *Tr. gubernaculum* (Reeve)). But these require further study.

I have no doubt that in other river-systems other species or groups may be found which are governed by the same law. But, on the other hand, *there are surely other forms which positively do not follow it,* and exhibit the same obesity all along the course of a river in which they are found.

This can be tested, of course, only in such forms which have a wide distribution, and are found both in large and small rivers. I have measured a number of such, but did not find any evidence for our law in the following cases.

Elliptio dilatatus (Raf.).—Distribution tremendous, equally abundant in large rivers and small streams: but no trace of the law observed.

Strophitus edentulus (Say).—The same wide distribution in all kinds of streams, but no evidence of the law.

(It should be noted that no species belonging to the subfamily *Anodontinas* has shown, so far, any evidence of submitting to this law.)

Ptychobranchus fasciolare (Raf.).—The same holds good for this species as for the two preceding ones.

Actinonaias carinata (Barn.) (= *Nephronaias ligamentina*).—Although not going into the smallest headwaters, this species is found in smaller and larger rivers, but no change of obesity is observed.

Eurynia recta latissima (Raf.).—Has a very wide distribution from the large rivers well up into the headwaters, but is remarkably uniform in obesity.

Lampsilis siliquoidea (Barn.) (= *luteola*).—Practically ubiquitous in the interior drainage (although missing in the upper Tennessee). No relation observed between size of stream and obesity, although the shell is very variable.

Lampsilis fasciola Raf. (= *multiradiata*).—Practically everywhere in the interior drainage, but obesity not responding to station.

Truncilla triquetra Raf.—Of wide distribution, and in streams of various size, but without marked change in obesity.

Truncilla capsaeformis (Lea).—Widely distributed and common in the upper Tennessee region, found in small creeks and large rivers, but uniform in the convexity of the valves.

In addition it should be remarked that in none of the species belonging to the Atlantic drainage this law has been observed to exist. This is most evident in the common *Elliptio complanatus* (Dillw.). This is found practically everywhere, in large rivers as well as in

small streams, and varies greatly in obesity. But no correlation between the diameter of the shell and the size of the stream has been discovered.

In the tables given above, one character has been brought out preëminently, that is *obesity*, or diameter of the shell as related to length.

But, in addition, another fact has been discovered, which is the following. *A shell which decreases in diameter in the headwaters, makes up, so to speak, for the loss by a gain in size, that is to say, in circumference, and this is best expressed by the total length of the shell.* The latter not having been given in the tables, I supplement this here for the several species discussed.

The following *maxima of length* have been observed (the large river form is given first; the headwaters form in the second place).

Fusconaia subrotunda: 107 mm.; *F. subr. kirtlandiana:* 133 mm.

Fusconaia pilaris: 70 mm.; *F. pil. lesueuriana:* 84 mm.; *F. pil. bursa-pastoris:* 100 mm. (Simpson gives even 110 mm. for the last one).

Fusconaia flava trigona: 67 mm.; *F. flava:* 90 mm. (This is not everywhere so striking, for locally the typical *flava* appears as a dwarfed race, as for instance in Crooked Creek in Pa., where the largest specimen is only 74 mm. long, but longer yet than the largest *trigona*.)

Fusconaia cuneolus appressa: 63 mm.; *F. cuneolus:* 68 mm.

Fusconaia edgariana: 63 mm.; *F. edg. analoga:* 70 mm.

Fusconaia barnesiana tumescens: 67 mm.; *F. barnesiana:* 77 mm.; *F. barn. bigbyensis:* 86 mm.

Lexingtonia dolabelloides: 56 mm.; *L. dol. conradi:* 68 mm.

Pleurobema oviforme holstonense: 58 mm.; *P. oviforme:* 68 mm.; *P. ovif. argenteum:* 96 mm.

Obovaria subrotunda: 59 mm.; *O. subr. lens:* 67 mm.

Only in *Pleurobema cordatum catillus* and *P. cord. coccineum* this phenomenon is not evident, and it could not be established in the case of *Dromus dromas* and *caperatus*. For the others, as may be seen by the above figures, it stands out as a striking fact, and cannot

be due, by any means, to accident. Thus we must accept it as demonstrated, *that in most shells which show a decrease in diameter in the upstream direction, this decrease is compensated, to a degree, by the greater size of the shell as expressed by its length.*

Further, we have seen in certain forms (*Quadrula metanevra* and *Qu. cylindrica, Dromus dromas*), that a peculiar kind of surface sculpture, namely large knobs and tubercles, tend to disappear in the headwaters. This is also connected, more or less distinctly, with a flattening of the shell. It would be interesting to discover additional cases of this kind, and may be found in *Truncilla torulosa* and *gubernaculum* of the upper Tennessee. But it surely is not a general law, since there are other shells, which show no change in sculpture along the course of a river, and since there are other instances, where the opposite seems to be the case. The group of *Amblema plicata* seems to belong here, where a strongly sculptured and flat form (*A. costata*) belongs to the headwaters, while a smoother and more swollen form (*peruviana*) is in the largest rivers.[22]

In this connection it should be pointed out, that a similar case is known in the freshwater Gastropod *Io*. The facts have been positively established by C. C. Adams[23]; a tuberculated or spinose form (*Io spinosa* Lea) is found in the larger streams; a smooth form (*Io fluvialis* Say) in the headwaters. The present writer is able to confirm this by his own observations. The smoothness of the specimens of *Io* in the upper Powell, Clinch, and Holston in Virginia is very striking; tuberculate individuals begin to appear farther down, and real spiny ones not till the state line of Tennessee is reached. The transition is quite gradual.

CONCLUSIONS.

Certain Naiades change their shape along the course of one and the same river in such a way, that

    1. the more obese (swollen) form is found farther down in the

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[22] See Wilson and Clark, '14, p. 63; Utterback, '16, p. 41.
[23] *Mem. Nat. Acad. Sci.,* 12, 1915.

large rivers, and passes gradually, in the upstream direction, into a less obese (compressed) form in the headwaters;

2. with the decrease in obesity often an increase in size (length) is correlated;

3. a few shells which have, in the larger rivers, a peculiar sculpture of large tubercles, lose these tubercles in the headwaters.

The question arises: *what is the meaning of these changes in shape?* No positive conclusion is as yet possible, chiefly for two reasons: first, that there are only some species (and comparatively few), in which this law is observed, while others positively do not show it; and in the second place, that, although the size of the stream undoubtedly is connected with this phenomenon, we do not know, whether *size alone is the essential factor,* or whether additional factors belonging to those constituting the small-stream-community are responsible.

A few points, however, should be mentioned, which might finally lead to or help in the proper understanding of the facts.

1. Practically all of the shells which show this phenomenon are of a rather primitive structure. The genera *Fusconaia, Amblema, Quadrula, Lexingtonia,* and *Pleurobema,* belong to the most primitive types of North American Naiades; and *Dromus* and *Obovaria* are comparatively primitive among the subfamily *Lampsilinæ.* No Naiades which stand on a high stage of differentiation have given any distinct evidence for our law.

2. It must not be forgotten that dispersal of almost all our Naiades is accomplished in the larval stage, when the larvæ live parasitic upon fishes, and that certain species of shells are restricted to certain species of fishes as hosts. Thus the distribution of the fish-host, and the ecological peculiarities of it, must largely influence the distribution of the Naiades. Since we have fishes which are migratory, while others are more stationary, it might be that Naiades living parasitic upon the latter kind have a smaller chance to be carried far away from their native grounds, while others, parasitic upon migratory fishes, are promiscuously scattered over the whole river-system, being often deposited far from their place of birth. In the first case, development of local races, in

consequence of reaction to local environmental conditions, is favored; in the second case, no such local development is possible, any tendency toward it being promptly obliterated by the mixing of the different stocks.

This, however, requires additional investigation. In most of the species, chiefly those from the upper Tennessee region, we do not possess sufficient information as to the fish host and its ecological habits. My chief purpose in the present paper was, to bring out the evidence for the actual existence of the law.

THE DISTRIBUTION OF LAND AND WATER ON THE EARTH.

By HARRY FIELDING REID.

(Read April 22, 1920.)

The shapes of the various continents and seas, their relative areas, and their dispositions with regard to each other, have always been attractive problems for geographers; and a number of characteristics have been formulated, which have been repeated in various text books of geography and geology, and have thus become familiar to us all. They are:

1. The earth can be divided into two hemispheres in such a way that nearly all the land is concentrated in one hemisphere, and the other is nearly all covered with water.

2. The land is everywhere opposite the water.

3. The land is concentrated around the arctic regions, and the water around the antarctic regions. The land sends three projections towards the south, and the oceans three projections towards the north.

5. The continents are roughly triangular in shape, pointing southward. The oceans are roughly triangular in shape, pointing northwards.

6. The continents are divided into a northern and a southern group by mediterranean seas; and the southern group is offset towards the east.

I imagine we have all pondered over these curious characteristics; and I must confess that the antipodal relation of land and water has, until recently, been to me an absorbing though baffling mystery, with no threads leading to its solution. But the matter turns out to be rather simple, after all. It can be shown that nearly all the characteristics enumerated above are comprised in the following: *The land area of the earth is a loosely connected, and deeply dissected area, about five-sixths of which is concentrated in*

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*one hemisphere, whose pole lies about half way between the equator
and the north geographic pole. And the position of this land area
on the earth has no relation whatever to the earth's equator and
axis of rotation.*

A glance at Fig. 1 will show that this is a true statement; we
shall discuss later this concentration of the land.
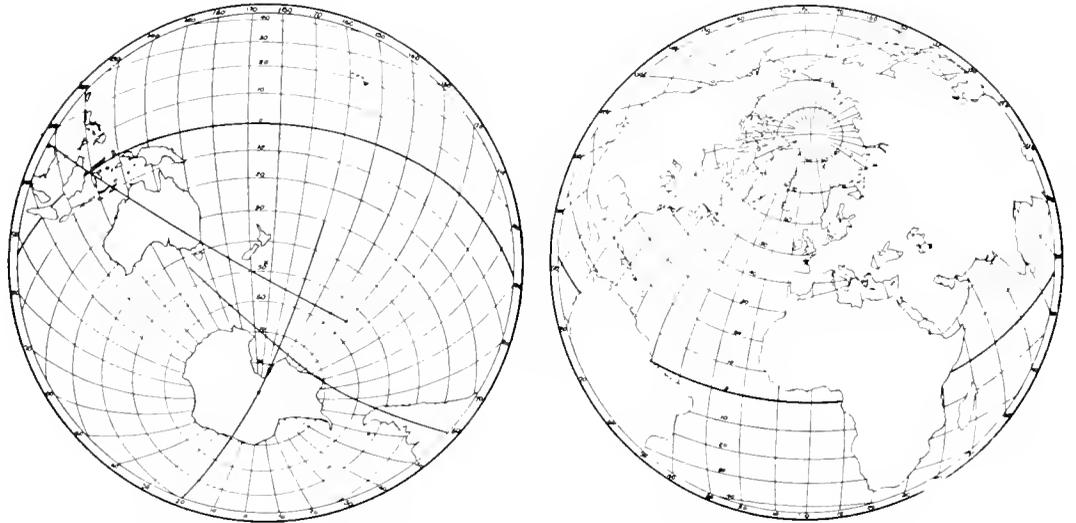
FIG. 1.   Land and water hemispheres.   Lambert's equivalent area projection.

1. The first characteristic is explicitly contained in the general
proposition above.

2. A glance at Fig. 2, taken from Stieler's Handatlas, impresses
one strongly with the antipodal relation of land and water; but
Fig. 3 gives a truer impression. The former shows the eastern
hemisphere with the western hemisphere projected through upon it,
the latter shows the land hemisphere with the water hemisphere
projected upon it.[1]

If all the land were in one hemisphere, then the antipodal rela-
tion of the land to the water would be perfect. But this is not so;
there is some land in the water hemisphere. Does it project upon
water in the land hemisphere?

[1] The center of the land hemisphere has been pretty carefully worked out
by H. Beythien ("Eine neue Bestimmung des Pols der Landhalbkugel," Dis-
sertation. Kiel und Leipsig, 1898) following a method suggested by Pro-
fessor Krümmel. He places the center at latitude $47\frac{1}{4}°$ N. and longitude
$2\frac{1}{2}°$ W., close to the mouth of the Loire. Using a slightly different method
I have corroborated his results.

Fig. 2. Antipodal relations. Globular projection. From Stieler's
Handatlas.

Fig. 3. Antipodal relation of land and water hemispheres.
Lambert's equivalent area projection.

There are three main land masses in the water hemisphere: Australia, with some of the large islands north of it; the Antarctic continent, and the southern end of South America; to these may be added the much smaller area of New Zealand. Fig. 3 shows that Australia projects against the North Atlantic Ocean; and some of the adjacent islands against the northern part of South America; the southern part of South America projects almost entirely against China; the Antarctic continent projects partly against the Arctic Ocean and partly against the lands surrounding it. New Zealand projects partly against Spain and partly against the adjacent sea. The total area of the lands in the water hemisphere is about one eleventh of the area of the hemisphere. A little less than one half this land projects against water and a little more than one half against land, and this is almost exactly the proportion we should expect if the land in the water hemisphere were distributed without any definite relation to the water in the land hemisphere. For in the latter the ratio of the land to the water is $1 : 1.1$; *i.e.*, practically one half the hemisphere is water and one half is land. So far then as the antipodal relation of land and water is not explained by the existence of a land and a water hemisphere, it is purely accidental; and there is no necessity to look for a special explanation for it.

3. The fact that the center of the land hemisphere is pretty far north, being a little more than half way from the equator to the north pole, places the arctic regions well within this hemisphere and therefore naturally surrounds them with land. And similarly the antarctic regions being well within the water hemisphere is naturally surrounded by water.

4. If you draw on a sheet of paper the outline of any fairly compact area and then divide it up by deep indentations, you will have left a figure with projections pointing roughly away from the center. Now this is exactly the characteristic of the land area of the world. The projections of South America, Africa, and Australia are said to point towards the south. Our predilection for referring everything to the earth's axis of rotation has blinded us to the fact that these projections of the land area point equally well towards the antipodes of the center of the land hemisphere, *i.e.*, in

a general way, away from the land mass; a relation which is a natural consequence of the concentration of the land in one general mass. The strong lines in Fig 1 are great circles extending the directions of the three projections.

But why should there be just three such masses? I can give no definite answer to this question and I am not sure that there is a real answer to it.[2] In a dissected land area, such as we find on the earth, there must be some number of projections, and the number will depend upon how broadly or how minutely the land is dissected; and their importance on how much we are impressed by the shape of the projections. Japan and Mexico, for instance, are quite as far from the center of the land hemisphere as the south end of Africa (see map, Fig. 1); but in their neighborhood the outline of the land maintains its distance from the center and we are not impressed by this distance.

5. The triangular shape of the continents and oceans is far too rough an approximation to have any real importance. A glance at special maps in a good atlas will show how far from triangular they are. South America is distinctly triangular; North America is not; Eurasia is not. Africa has more the shape of a carpenter's square. The northern part of the Pacific Ocean is bounded nearly by a great circle, that is the boundary is as nearly a straight line as can be drawn on the globe. Here again the maps made on a Mercator projection have suggested the idea of an ocean narrowing towards the north. The boundary of the Indian Ocean on the north is nearly a small circle, not in the least a corner of a triangle. Nor do the North and South Atlantic Oceans at all follow a triangular shape. I think the suggestion of a triangular shape for the oceans and continents is too vague to have any meaning or any value and may be abandoned.

6. Is this of real significance? South America is certainly well separated from North America; and Australia from Asia; but Australia is really a very big island and is only a continent by courtesy. The separation of Africa from Europe is quite insignificant. It has been suggested that the mediterraneans are the indications of a zone of weakness lying along what was once the earth's

[2] See, however, a few pages further on.

equator, with the pole in Behring's sea; that the southern hemisphere contracted more than the northern and thus tended to increase its rate of rotation, producing stresses which caused fractures
along the then equator. Aside from dynamical objections to such
a process, we note that Africa is not offset along the Mediterranean;
only its southern part is offset. So that the explanation offered
does not apply to the conditions in attempts to explain. Here again
our predilection for the geographical north and south line brings its
influence to bear, and we think that the continents should naturally
lie north and south, and that any deviation from that direction needs
an explanation. But this is not so. In this particular case, however, the southern ends of·the three land projections lie all three
somewhat to the east of the northern parts, and this uniformity is
striking. But notice this: if these southern ends do not lie directly
south of the northern parts, two of them must be apparently displaced in one direction; the third might be displaced in the same or
in the opposite direction; that it should happen to be in the same
direction is not remarkable.

I think, therefore, we may agree that the main characteristics of
the distribution of land and water on the globe is contained in the
statement given in italics near the beginning of this paper.

Why should we have a land hemisphere and a water hemisphere?
The answer given by Herschel, about 60 years ago, is the true
answer, though to be sure, it only points the direction in which
further knowledge should be sought. Herschel's explanation was
that the center of mass of the earth and its center of figure do not
coincide.

Let us examine this a little more closely. If the material of the
earth were distributed with perfect symmetry about the center of
mass the ocean would cover the whole earth to a uniform depth.
But if one hemisphere were slightly denser than the other the water
would be drawn to that side and make a deeper ocean there.

How can we explain this lack of symmetry? We could easily
imagine that the earth, in whatever manner it may have developed,
might be lacking in symmetry sufficient to bring about the small
separation, about a mile and a half, between its center of mass and

its center of figure. This would infer the permanence of the Pacific Ocean, still a moot question among geologists; and we must also remember that Hayford and Bowie have shown that under the continent of North America, and, in a less convincing degree, under the adjoining oceans, isostatic adjustment is complete at a very small depth; and it is only in this surface skin therefore that the density of the earth is different in the two hemispheres. In many parts of the known continental areas the rock has undergone changes of density, with correcponding changes of level; whether such changes have extended over very large areas so as materially to change the distribution of land and water on the globe is the still unanswered problem of the permanence of the ocean basins. Imagine an earth, spherically symmetrical in density; now imagine that the crust in one hemisphere to a depth of 100 miles contracts so as to shorten the central radius by 3 miles and that this shortening gradually diminishes to zero along the edge of the hemisphere. A simple calculation shows that the crust to a depth of 100 miles would be increased in density about 3 per cent.; that the center of mass of the earth would be displaced only about 70 feet, so that the level surfaces would remain practically unchanged; and therefore the ocean in the center of the contracted hemisphere would be about 3 miles deeper than in the antipodal region. This apparently is what has occurred, but why the contraction should be especially marked and so general over one hemisphere is still unknown.

The only attempt to explain the hemispherical distribution of density is that of Osmond Fisher.[3] He suggests that the material that formed the moon, according to George H. Darwin's theory, was collected from the superficial part of the region which is now the Pacific Ocean, and was therefore of comparatively small density. The scar was healed, to a large extent, by denser material from below, and the two Americas were, at the time of separation of the moon, cracked off from Europe and Africa, and floated to the west, leaving the Atlantic basin underlaid by the denser material below. This hypothesis is purely speculative. It runs counter to other geo-

[3] *Nature,* 1882, XXV., 243; also "Physics of the Earth's Crust," 2d ed., 1889, XXV. W. H. Pickering offered the same explanation. "The Place of Origin of the Moon," *Jour. Geol.,* 1907, XV., 23–38.

logical speculations, such as a land connection between Africa and
Brazil in middle geologic times, and a similar connection across the
North Atlantic in Tertiary times.

Some attempts have been made to explain the existence of oceans
and continents. Lowthian Green advanced the tetrahedral hypoth-
esis in 1875.[4] The corners and edges of the tetrahedron are sup-
posed to be land areas, and the faces water areas. The advocates
of this hypothesis differ materially in locating the corners and the
edges; and the dynamical arguments in favor of the tetrahedral
form are entirely unsound.

In 1878 George Darwin[5] suggested that under the tidal action
of the moon north-south wrinkles might develop, which would later,
under the same forces, have their equatorial portions pulled towards
the west. The general form of the continents conform but slightly
to this plan, and the geologic structure is largely at variance with it.

The idea of an earth cooling and contracting goes back to the
time of Leibnitz. Dana[6] suggested that the portions of the earth's
crust which solidified first would blanket the rock under them and
keep it warm; these regions would become continents; whereas,
violent convection in the still liquid regions would bring more heat
to the surface there and dissipate it, thus cooling these parts, and
causing them to contract more and become the ocean beds.

Pratt's studies of the deflection of the vertical in India led him
to the conception now denoted by the name of isostasy; he con-
sidered that the difference of density under the continents and
oceans was due to unequal contraction, but he did not assign any
cause of this inequality.[7]

Faye,[8] accepting Pratt's conclusions, ascribed the greater density
under the ocean to the lower temperature there. Taking the tem-
perature of the sea bottom at a depth of 4000 m. at $1°$ C., the mean
surface temperature of the land (at sea level) at $16°$, and the tem-

[4] "Vestiges of a Molten Globe," Honolulu, 1875.

[5] Problems Connected with the Tides of a Viscous Spheroid," *Proc. R. S.*, 1878, XXVIII., 194–199, and *Phil. Trans. R. S.*, 1879, CLVII., 539–593.

[6] "On the Volcanoes of the Moon," *Amer. Jour. Sci.*, 1846, II., 335–355.

[7] "Figure of the Earth," 4th ed., 1871, pp. 201, 202.

[8] "Sur les variations séulaires de la figure mathematique de la Terre," *C. R.*, 1880, XC., 1189–91.

perature gradient at $1°$ C. per 33 m. the temperature under the land at the same level as the sea bottom would be $16° + \dfrac{4000}{33} = 149°$.

Trabert[9] carried Faye's idea a step farther. He assumes a land surface temperature of $10°$ C., a temperature gradient of $3°$ per 100 meters, and a mean ocean depth of 4300 meters, with a bottom temperature of $0°$; and thus gets a difference of $140°$. He then calculates what would be the difference of average temperature of two cones, extending to the earth's center, one under the land and one under the sea, sufficient to account for a difference in length of 5000 meters, which he gets roughly by adding the mean height of the land to the mean depth of the ocean. He finds the relation $aRT = 5000$ m., where $a = .00001$ is the coefficient of expansion of the rock, R the radius of the earth, and T the average difference of temperature of the two cones. This gives $T = 78°$, which, in view of the difference of temperature of the sea bottom and the same level under the land, he considers a very reasonable figure; and therefore thinks the ocean basins are entirely due to low temperature of the underlying rock.

But it is quite impossible for the two cones to differ by anything like $78°$ in mean temperature. Both Faye and Trabert were misled by comparing the temperatures at the sea bottom level. This difference has no bearing whatever on the difference in the mean temperatures of the two cones. To illustrate: Suppose we have two cones of exactly the same size, and with a similar distribution of temperature; for simplicity, suppose the temperature is diminishing continuously from the apex to the base. Now let one of these cones expand uniformly, each of its elements keeping its temperature. Its mean temperature will not have changed at all; it will still be the same as that of the other cone; but at the same distance from the apex it will have a higher temperature than the other cone. It is easy to imagine a distribution of temperature which would yield a great difference between the two cones at the level of the base of the unchanged one; though the mean temperatures of the two cones

[9] "Eine mögliche Ursache der Vertiefung der Meere," *Sitz. Kais. Ak. Wiss. Wien, Math. Nat. Kl.,* 1911, Bd. 120, Abt. 2 *A,* 175–180.

remain the same. All that is necessary is that the temperatures should change rapidly near the bases of the cones.

Let us calculate the difference of mean temperature of the land and sea cones under some simple distributions of temperature. Suppose the apices of the cones to have the same temperature and the bases to differ by 16° C.; and suppose the temperature gradient to be uniform in each cone from the apex to the base. An easy calculation shows that the difference of the mean temperature of the cones would be three quarters of 16°, or 12°. And with the coefficient of expansion adopted by Trabert, this would account for a difference of level of the bases of 770 meters, or about one seventh of the actual amount. A constant temperature gradient in the earth is of course impossible. With a gradient of 1° per 100 meters, which is certainly smaller than that observed at the surface, we should have a central temperature of over 127,000°.

As a second example let us suppose that the earth has cooled in accordance with Lord Kelvin's theory. We shall take the original temperature at 1170°, the present land surface temperature at 16°, the sea bottom at 0°. For the sake of making the difference as great as possible, we shall assume an age for the earth of 500 million years. We find that below a depth of one tenth of the radius the two cones have practically the same temperature and that the mean difference in the two shells above this depth is somewhat less than 4°, accounting for a difference of level of the bases of the two cones of about 25 meters.

If we ascribe the earth's heat to radioactive substances, we are confronted with our ignorance of the relative quantities under the land and under the sea. They seem to be somewhat more abundant in the more siliceous rocks of continental areas, though the red clay of the deep sea seems to have a high content; on the other hand the less siliceous rocks of the oceanic areas have a lower conductivity for heat. We may then as a rough approximation assume that the temperature curve has the same form under the two regions, differing, however, by 16° in temperature at the same depth below the surface. This would only hold for moderate depths, say, for a few hundred miles. Farther than this there would be a diminution

of the difference due to the flow of heat from the regions below the continents to those below the oceans, so that the mean difference of our two cones would be less than 16°. A mean difference of 16° would account for about 1000 meters difference of level at the earth's surface.

It seems difficult to imagine any probable distribution of temperature in the earth that would cause a difference as much as 16° in the mean temperature difference of oceanic and continental cones. And this is only about one-fifth as much as Trabert asks to account for the difference of elevation of 5000 meters; and when we consider that there are considerable tracts of sea bottom and of plateau land that differ in level by twice that amount it seems to exclude a mere difference of temperature as a sufficient cause of the different levels of the earth's surface. As further confirmation of this conclusion we notice that the antarctic continent and Greenland are buried under ice which keeps their surface temperature quite as low as the sea bottom, and still they are both land areas.

Joseph LeConte[10] ascribed the ocean basins to greater cooling and contraction on account of greater conductivity for heat of the underlying material. What little information we have on this subject is opposed to the idea. For basaltic rocks, which characterize the oceanic areas, have a smaller conductivity and diffusibility than the granitic rocks, which are mainly continental, or the sedimentaries.

Sollas[11] has suggested the following, on the hypothesis of a cooling earth: When the earth was still very hot, all the water would be in the atmosphere as vapor, and would exert practically a uniform pressure on all parts of the earth. When the temperature fell sufficiently for this water to exist in a liquid form it would occupy the slight depressions which must have existed, increasing the pressure there and reducing the pressure over the high regions As the crust of the earth was then very near its melting point and the pressure due to the water was important, there may have been considerable compression under the oceans and expansion else-

[10] " A Theory of the Formation of the Great Features of the Earth's Surface," *Amer. Jour. Sci.*, 1872, IV., 345–355, 460–472.

[11] *B. A. A. S.*, 1900, pp. 714–716.

where, combined with a squeezing out of some material from under the seas. It is not clear how this expansion could have been maintained as the crust cooled.

Chamberlin thinks that the earth is divided into six segments, three in the northern hemisphere and three in the southern; that the edges of these segments would be squeezed up leaving the depressed faces as the incipient ocean basins; that a preponderance of heavier planetesimal matter was deposited under areas of high barometer; that there were three such areas in the southern hemisphere, partly on account of the three segments, but also on account of "the peculiar spacial requirements of a hemisphere."[12] (It may be remarked that this requirement of a hemisphere is not recognized by mathematicians, geophysicists, or meteorologists, and there are only two areas of high pressure in the northern hemisphere, which also change with the seasons.) Chamberlin also thinks that the heavier materials in the crust were carried by erosion to the oceans leaving lighter materials on the continents; and the accumulation of heavier material perpetuated and accentuated the ocean basins. The hypotheses on which this explanation is based are far too numerous to make it at all acceptable.

In 1873 Dana looked upon the greater density under the ocean as due to the character of the mineral ingredients there, but could not account for their distribution.[13] Iddings has pointed out that the rocks collected from the Pacific islands, have, on account of their composition, a higher density than the rocks of the continents, and, so far as our knowledge goes, fit in with the general principle of isostasy.[14]

We may say, in closing, that the existence of a water hemisphere and a land hemisphere is due to the non-coincidence of the center of mass and the center of figure of the earth; that this is due to a difference of density in the two hemispheres, probably confined to a hundred miles or so of the surface; and that this, in turn, is due, not to unequal contraction or anything of that kind, but to a difference in the composition of the rock in the two areas.

[12] "The Origin of the Earth," Chap. VIII., Chicago, 1916.
[13] *Amer. Jour. Sci.*, 1873, VI., 168–169.
[14] "The Problem of Volcanism," pp. 123–125.

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2. Persons of any nation, sect or denomination whatever, shall be admitted as candidates for this premium.

3. No discovery, invention or improvement shall be entitled to this premium which hath been already published, or for which the author hath been publicly rewarded elsewhere.

4. The candidate shall communicate his discovery, invention or improvement, either in the English, French, German, or Latin language.

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PROCEEDINGS

OF THE

American Philosophical Society

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CONTENTS

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Essays must be typewritten on only one side of the paper, and six copies must be furnished by their respective authors for the use of the Committee of Judges.

The literary property of such essays shall be in their author, subject to the right of the Society to publish the crowned essay in its " Transactions " or " Proceedings."

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THE TRANSIENT PROCESS OF ESTABLISHING A STEADILY ALTERNATING CURRENT ON A LONG LINE, FROM LABORATORY MEASURE-MENTS ON AN ARTIFICIAL LINE.

By A. E. KENNELLY and U. NABESHIMA.

(Read April 22, 1920.)

The purpose of this paper is to make a contribution to the theory, records and measurement technique of transient electromagnetic wave propagation over long uniform conductors, with particular reference to the upbuilding of the alternating-current steady state over long alternating-current power-transmission lines, from measurements made on artificial power-transmission lines in the laboratory.

As is shown in the appended bibliography, the subject has been already developed to a considerable extent from the theoretical side. Very little, however, seems to have been published on the practical side. The research here described has been mainly directed to the practical side of the subject, from the laboratory viewpoint. It was taken up in October, 1917, in thesis work towards a master's degree.[1] It was later continued from May, 1919, to the present date, as a research in the electrical Research Division at the Massachusetts Institute of Technology.

Classification of Transients.—For the purposes of discussion and analysis, it is desirable to establish certain provisional definitions relating to transient electromagnetic phenomena, in order to avoid ambiguity.

A transient may be defined as a temporary and evanescent disturbance in an electric circuit, or in the indications of apparatus connected therewith, due to any arbitrary sudden change imposed

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[1] Bibliography 36.

upon the circuit. A permanent or steady electromagnetic state cannot therefore contain transients to any appreciable extent; although transients will probably have been involved in the production of that state. It is true that transient phenomena persist with progressive attentuation for an indefinitely long period, and, in that sense, never completely disappear. From an engineering point of view, however, transients diminish into practical negligibility in a period of time that is ordinarily measured in milliseconds; so that they may be regarded as having vanished, when the steady state is accepted as having been attained.

For the purposes of discussion, transients are subdivided as shown in Table I.

Class *A* includes transients of all kinds, mechanical and electrical. Thus, a kick of the pen of a recording ammeter pointer might represent a mechanical transient due to an electrical transient.

Prominent among transients are electromagnetic-wave transient disturbances, or *wave transients*.

An important class of wave transients are those which accompany the establishment of an alternating current over a line. These may be classed collectively as initiating *a.-c. transients*. This is the principal class of transients discussed in this paper.

Initiating alternating-current wave transients occur, in general, whenever a switch is closed at the generating end of an *a.-c.* line. If the switch could be closed in such a manner as to produce no electric " splash," the outgoing wave transient would be the " regular " transient, which accompanies the regular formation of the final alternating-current state.

Infinite Distortionless Line Closed at Zero E.m.f. (No Transients).—If we assume, for simplicity, a perfectly regulated sine-wave generator, of negligible internal impedance, connected as in Fig. 1 to an indefinitely long uniform distortionless line,[2] then if the switch *S* is closed at some instant when the alternating e.m.f. is passing through zero, the initial outgoing waves of e.m.f. and cur-

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[2] A distortionless line was originally defined by Heaviside as a line in which $l/r = c/g$. In such a line, the surge impedance z_0 must have zero slope at all frequencies, or becomes reactanceless. See Bibliography (1), page 126, Vol. II.; also Bibliography (30), page 154.

TABLE I.

PROVISIONAL CLASSIFICATION OF TRANSIENTS.

Transients [A]

- [B] Mechanical transient
- [C] Energy transient
- [D] Power transient
- [E] Electro-magnetic transient
  - [F'] Electromagnetic radiation transient (in air)
  - [F] Electromagnetic wave transient (on conductor)
    - [G] D. C. wave transient
    - [II] A. C. wave transient
      - [I] Casual A. C. wave transient
      - [I'] Terminating A. C. wave transient
      - [J] Initiating A. C. wave transient
        - [K] Lumpiness transient
        - [L] Splash transient — of e.m.f. and current
        - [M] Regular transient

rent will be splashless; *i.e.*, they will be sinusoidal and in cophase from the very start. In such a case, because there can be no reflection from the distant end, the initial outgoing current will be the same, both as to magnitude and phase, as the final outgoing
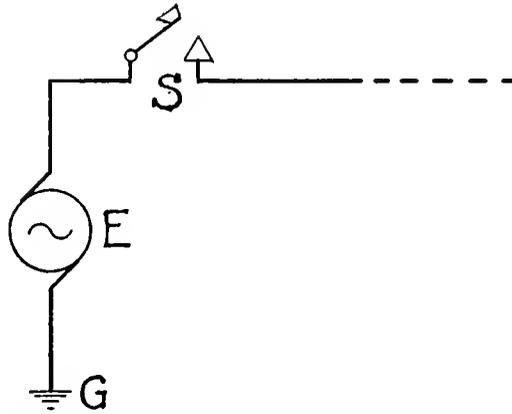
FIG. 1.   Diagram of A. C. Generator Connected to Line.

current; or there will be no transient wave.   In this particular and simple case, if z_0 is the reactanceless surge impedance of the line, in ohms, E_A the maximum cyclic e.m.f. in vector volts at standard phase, the initial and final outgoing current will be

$$I_0 = \frac{E_A}{z_0}, \quad \text{max. cyc. amperes } \angle . \quad (1)$$

If the frequency of the impressed e.m.f. is f cycles per second, and the corresponding angular velocity $\omega = 2\pi f$ radians per second, then, at time t seconds after the switch closure, the instantaneous voltage and current at A will be

$$e = E_A \sin \omega t \quad \text{instantaneous volts,} \quad (2)$$

$$i = \frac{E_A}{z_0} \sin \omega t \quad \text{instantaneous amperes.} \quad (3)$$

Because of the simple conditions assumed in this case, including infinite line length, the current defined by (3) is instantly developed without the intervention of any transient.   If the line has finite length, but is grounded at B through an impedance equal to the surge impedance z_0, it will give rise to no reflections from B, and will behave, in this respect, like a line of infinite length.   Such a case is represented in Fig. 12 (film 35).

Finite Smooth Distortionless Line closed at Zero E.m.f. (*Regular Transients*).—If, instead of assuming an infinite line, or its equivalent—a line of finite length AB, grounded at B through a resistance equal to the surge resistance z_0—we apply the above stated conditions to a finite smooth line, grounded at B through some other impedance, reflected waves of voltage and current will return to the generating end A, and will add themselves to the outgoing stream. These successive increments build up regularly into the steady state, at each and every point along the line.[3] The initial outgoing e.m.f and current are therefore transients in this case, as are also all the reflected increments. Such wave transients may therefore be described as " regular " wave transients, because their regular superposition and combination bring about the final steady state.

Finite Smooth Line, with Distortion, Closed at Zero E.m.f. (*Splash Transients*).—If the uniform smooth line AB is not only finite; but also has distortion, its surge impedance z_0 will contain reactance, and have some angle or slope. In the steadily alternating-current state, therefore, at any point along the line, the current and voltage will not, in general, be in cophase. At an instant of zero current, there will be some e.m.f. and at any instant of zero
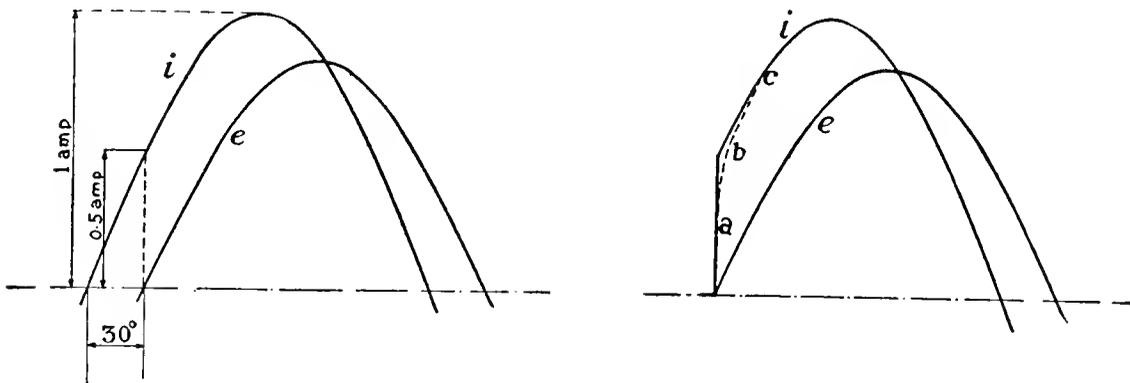
Fig. 2a.

Fig. 2b.

Illustrating formation of a Current Splash Transient.

e.m.f. there will be some current. Consequently, if the switch is closed at an instant of zero e.m.f., there will be some accompanying " electric splash "; because the current is then forced to start from zero coincidently with the e.m.f. In Fig. 2a, the wave i of

[3] Bibliography 6, and 13 page 79.

normally outgoing current is represented as leading, by 30°, the associated outgoing wave e of e.m.f.; so that at an instant of zero e.m.f., the strength of the current will be 0.5 ampere. In Fig. 2b, the switch at the generator end of the line is supposed to be closed at an instant of zero e.m.f. The instantaneous outgoing current must also be zero at that moment. The first outgoing half wave of current is therefore distorted from the sinusoidal form, and follows a course such as is indicated approximately by the dotted line abc. This distortion gives rise to a splash transient.

A splash wave transient may therefore be defined as that transient wave disturbance which is due either to closing the line switch at a moment when the generator e.m.f. is off zero; or, if the generator e.m.f. is zero, to the zero of line current forced at that instant, when the surge impedance of the line calls for a definite phase difference between outgoing current and voltage. In general, the splash transient will be greater, the greater the value of the impressed e.m.f. at switch closure. The splash can only be zero in the case of a distortionless line closed at an instant of zero e.m.f. It may, however, be expected to be a minimum, on any ordinary line, when closed at or near an instant of zero e.m.f.; because if there is no e.m.f. splash, the current splash is usually very small.

Lumpy Artificial Line Closed at Zero E.M.F. Lumpiness Transients.—If an artificial line, made up of alternate coils and condensers, is used in place of a smooth and uniform line; the lumpiness of the line will give rise to another type of transient,[4] which may be called a " lumpiness " transient. This lumpiness transient may be regarded as being produced by oscillatory disturbances between the successive coils and condensers. Lumpiness transients are magnified by the sudden application of a large e.m.f. In other words, the conditions which produce splash transients on smooth lines are also those which favor lumpiness transients on artificial lines. In laboratory measurements of lumpy artificial lines, lumpiness transients must therefore be expected over and above the transients due to splash.

Table I. presents a provisional classification of transients con-

[4] Bibliography 37.

nected with electric circuits. These may be divided into subclasses in a variety of ways. The transients particularly discussed in this paper are the regular transients M, which are a branch of the initiating a.-c. wave transients, and which belong to the principal class A through subdivisions E, F, H, and J.

Artificial Line Employed.—The measurements reported in this paper were all carried out on an artificial line in the electric transmission laboratory of the Massachusetts Institute of Technology. This is an artificial power-transmission line of 26 π-sections, designed by Drs. Pender and Huxley, the construction and dimensions of which have been described elsewhere.[5] It represents an aërial singlephase copper conductor of 253 sq. mm. (500,000 cir. mils) cross section, using ground or neutral return, and having the constants given in the following table.

TABLE II.

Particulars of the Artificial Line Chiefly Used in Tests.

Length of Conjugate Smooth Line per section ......48.28 km. 30 miles
Total of 26 sections .... 1255 km. 780 miles

	Whole Line.	Per Section.
Conductor Res: R at 19° C., ohms	87.71	3.374
Inductance L, henrys	1.457	0.05605
Reactance X, at 60.6 ∿, ohms 555		21.345
Dielectric Leakance G, mhos	15.14×10^{-6}	0.5823×10^{-6}
Dielectric Capacitance C, farads	12.58×10^{-6}	0.4838×10^{-6}
Dielectric Susceptance B, at 60.6 ∿, mhos	4.790×10^{-3}	0.1842×10^{-3}

Linear Constants.	Per Wire Km.	Per Wire Mile.
Linear Resistance r at 19° C., ohms	0.06987	0.11245
Linear Inductance l, henrys	1.1611×10^{-3}	1.8683×10^{-3}
Linear Reactance x, at 60.6 ∿, ohms	0.4421	0.7115
Linear Leakance g, mhos	1.206×10^{-8}	1.941×10^{-8}
Linear Capacitance c, farads	1.002×10^{-8}	1.6127×10^{-8}
Linear Susceptance b, at 60.6 ∿, mhos	3.816×10^{-6}	6.141×10^{-6}

Surge Impedance z_0 of line, or of a section, at 60.6 ∿, 342.5⌐ 4° 24′ ohms ∠
Angle Θ subtended by whole line, at 60.6 ∿,
    $1.6405\angle85° 25′8″ = 0.1315 + j\ 1.6352 = 0.1315 + j\ \underline{1.041}$ hyps ∠.
Angle θ subtended by single section, at 60.6 ∿,

[5] Bibliography 17*a* and 30.

$0.0631\angle85°\ 25'\ 8'' = (5.058 + j\ \underline{40.04})\ \text{10}^{-3}\ \text{hyps}\ \angle.$

Linear angle α at 60.6 $\sim$,

$1.307 \times \text{10}^{-3}\angle85°\ 25'\ 8'' = (0.1048 + j\ 1.302)\ \text{10}^{-3}$

$= (0.1048 + j\ \underline{0.8293})\ \text{10}^{-3}\ \text{hyp/km.}$

Linear angle α at 60.6 $\sim$,

$2.103 \times \text{10}^{-3}\angle85°\ 25'\ 8'' = (0.1686 + j\ 2.096)\ \text{10}^{-3}$

$= (0.1686 + j\ \underline{1.335})\ \text{10}^{-3}\ \text{hyp/mile.}$

Lumpiness correction of line, or of any section, in steady state, at 60.6 $\sim$,

$$\frac{\theta}{2}\Big/\sinh\frac{\theta}{2} = 1.0002\ \overline{\diagdown}\ 0°.0002.$$

The lumpiness correction factor of this line in the steady state is $1.0002\ \overline{\diagdown}\ 0°.0002$ at 60 $\sim$, which, for practical purposes, is quite insignificant. This means that, for a.-c. transmission in the steady state, at 60 $\sim$, this lumpy artificial line is equivalant to the smooth uniform line having the linear constants r, g, l and c of Table II. At 189.4 $\sim$, however, the lumpiness correction factor, in the steady state, is $1.002\ \overline{\diagdown}\ 0°.01$, and at yet higher frequencies, it becomes very appreciable. A picture of part of this line appears in Fig. 8.

In most of the measurements of transients made on this line, the full length of 26 sections, 1255 km., or 780 miles, was employed. At 60.6 $\sim$ —the frequency ordinarily used—this length is nearly a quarter wavelength,[6] so that, in the steady state, with the distant end B free, the voltage at B with the oscillograph connected there, rises to $5.627\ \overline{\diagdown}\ 110°.6$ times the voltage impressed at A.

Electrical Connections.—The electrical connections most frequently employed in the tests are indicated in Fig. 3. AB is the
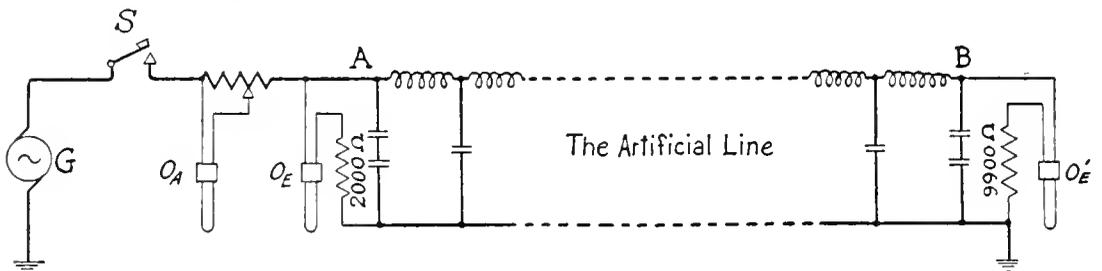
Fig. 3. Electrical Connections of Artificial Line.

artificial π line. At the generator end A, is a single-pole motor-controlled line switch S, for closing the circuit at any desired phase of e.m.f. from the alternator G. A current-recording oscillograph

[6] Bibliography 13, p. 82.

O_A records the initial current waves entering the line for the first few cycles after the switch S is closed. The voltage-recording oscillograph O_E records simultaneously the wave form of the impressed e.m.f. The distant or receiving end B, is freed in Fig. 3, except that it is connected to ground through the high non-inductive resistance, ordinarily of 9900 ohms, in order to permit of operating the voltage-recording oscillograph O_E'. All three oscillographs are set into operation simultaneously, on closing the phase-selecting switch S, during about 8 cycles from the 60 $\sim$ generator G, or for a duration of about $\frac{2}{15}$ second; and all three are recorded on the same photographic film 8.25 cm. ($3\frac{1}{4}$ inches) wide. In this manner, the voltage at each end of the line, and the current at the entering end, are recorded immediately after closing the line switch S.

Alternating-Current Generator.—The a.-c. generator G, Fig. 3, was a 6-pole 10-k.v.a. alternator of the Lauffen type, designed by Prof. C. A. Adams, for the delivery of a nearly pure sine-wave e.m.f. At the time these tests were made, no other load was connected to the machine. It was driven by a directly coupled d.-c. 110-volt motor, of approximately 10 kw. continuous rating, rotating at approximately 1200 r.p.m. The current in the d.-c. motor field magnet was adjusted in the testing room, so as to maintain constant frequency. The frequency was measured in the testing room by mounting a stroboscopic disk on the shaft of the small synchronous motor, and observing this revolving disk, illuminated by a fixed incandescent lamp, through slits in the prongs of a stroboscopic[7] fork on a telescope. Unless in such measurement, the frequency is held constant, the results are of little value.

Oscillograph.—The oscillograph had three vibrators, in an electromagnetic field common to all. The instrument was designed and constructed by Mr. H. G. Crane, at Harvard University. The bifilar vibrators had a working length of 12.5 mm., and were damped in castor oil. As the currents observed were of low frequency, the correction factors for frequency of the vibrators[8] are insignificant at 60 $\sim$, and are omitted.

[7] Bibliography 7.
[8] Bibliography 39.

Ammeters and voltmeters of the alternating-current type were introduced, at special times, into the artificial-line circuits, in order to secure calibrations of the oscillograms. The impressed e.m.f. at A ranged, in different cases, from 60 to 100 volts r.m.s.

Line-Switch Connections.—In order to minimize splash transients, it was necessary to design and make up a switch, which would connect the 60 ~ alternator to the artificial line at an instant of zero e.m.f. For this purpose, a little 6-pole synchronous motor, running in synchronism with the a.-c. generator, was caused to drive an insulating disk D, Fig. 4, carrying a 60° conducting sector
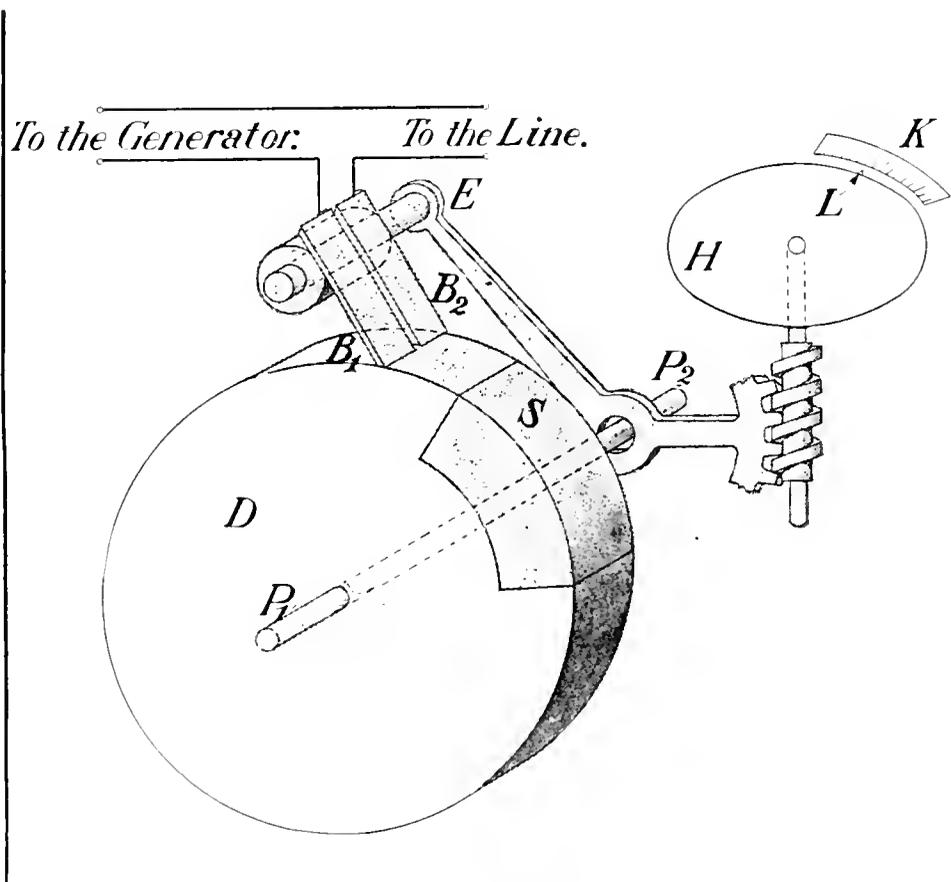
Fig. 4.   Brush Mechanism.

S, in such a manner that a pair of insulated brushes B_1B_2, resting thereon, could be brought into contact, through the sector, at any desired position around its circumference. The final adjustment of phase position was secured by means of the graduated pointer and scale LK, divided into single degrees of arc. One electrical degree

of phase shift corresponds to 24° of LK mechanical-arc adjustment. This adjustment is also illustrated in Fig. 5, where the pointer P
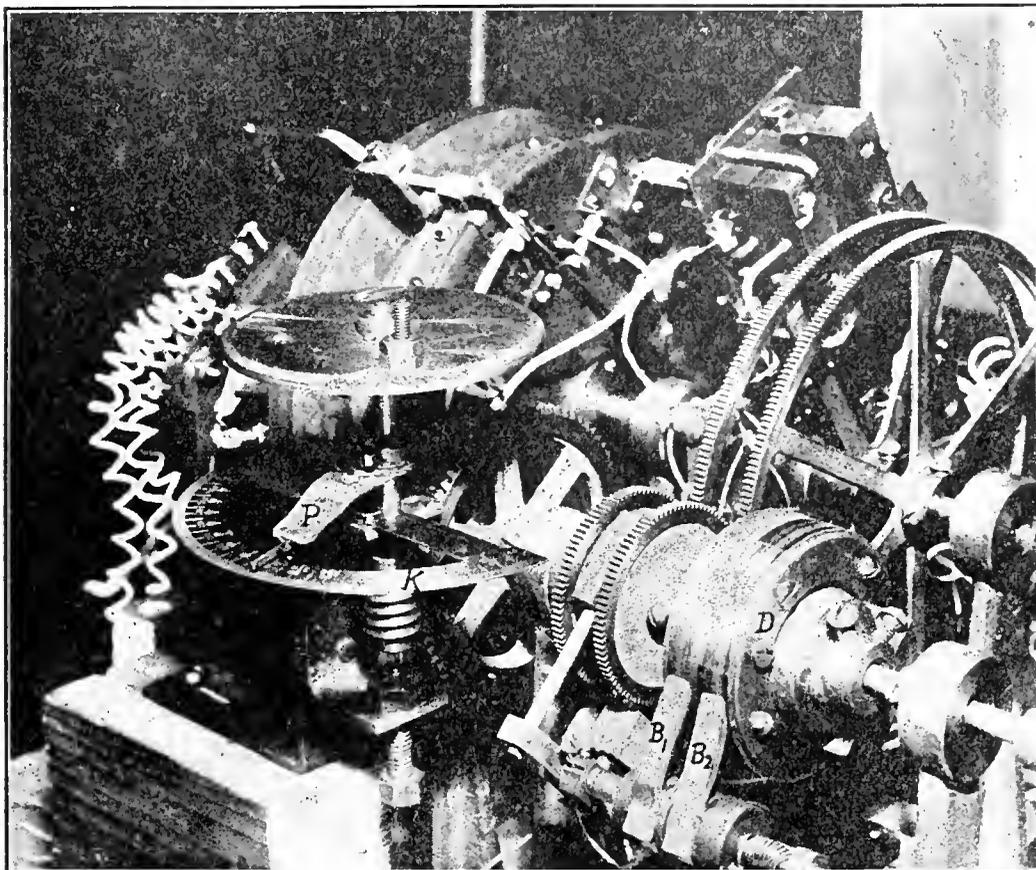
FIG. 5. Time-controlling Mechanism of Circuit-closing Switch.

stands over the stationary scale K, and determines the position of the brushes B_1B_2 around the sectored insulating disk D. One electrical degree of a 60 $\sim$ alternator corresponds to $\frac{1}{21600}$ of a second,
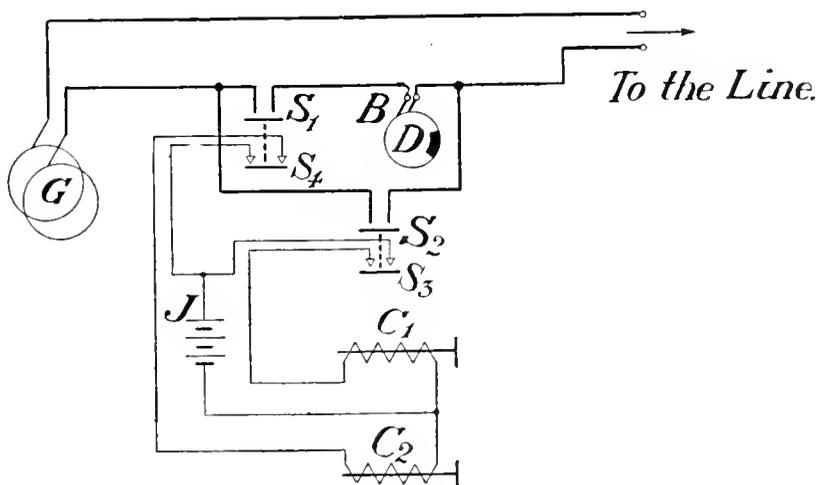
FIG. 6. Switch Diagram.

or 46.3 microseconds, so that, theoretically, 1 degree of arc in the setting of the pointer P corresponds approximately to 2 microseconds of time.

Technique of Making Records.—The electrical connections of the switch mechanism are indicated in outline by Fig. 6. The alternating-current generator G, is supposed to be in regular operation at the correct frequency. The above mentioned synchronous motor, shown in plan view in Fig. 7, is then started, and synchron-
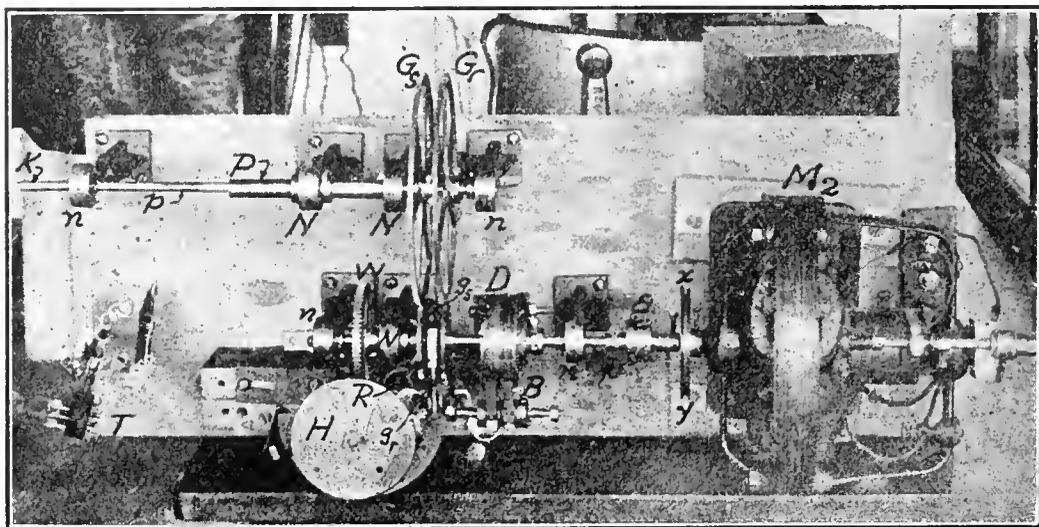
Fig. 7. Plan View of Synchronous Motor and Circuit-closing Switch.

ized with the generator. The arc lamp for the oscillograph vibrators is then lit. The brushes B_1B_2, Fig. 4, are next set in the correct position to close the generator on the artificial line at an instant of zero e.m.f. This adjustment is made by trial, substituting a simple non-inductive resistance for the artificial line, and closing the generator through the brushes, and an oscillograph, so as to observe on the translucent screen whether the beam of light starts into vibration without a splash. The setting of the brushes to effect this result can usually be adjusted, with ordinary optical conditions, within one electrical degree, or 46 microseconds for a 60 ~ generator. The artificial line is then reconnected to the apparatus, all ready for the photographic record. A starting lever is moved by hand, and this causes automatic switch S_1 to be closed, ahead of the rotary switch D. The brushes B_1B_2 then close the circuit finally,

at the proper predetermined phase of minimum splash. The automatic switch S_2 then immediately follows, so as to keep the contact closed on the line after the brushes $B_1 B_2$ have passed off the contact segment. Before the brushes $B_1 B_2$ close, the photographic shutter is opened by the electromagnet C_1, under the action of an automatic switch S_3. After one complete revolution of the photographic-film drum, another shutter is closed by the electromagnet C_2, under the control of an auxiliary automatic switch S_4. This cuts off the arc light from the recording film, after about nine cycles have been recorded on all three oscillographs. The whole mechanism can then be arrested, by hand, at leisure. Lastly, the photographic drum is removed and taken to the dark room for development.

A photographic view of the artificial line and the oscillographic apparatus is shown in Fig. 8.
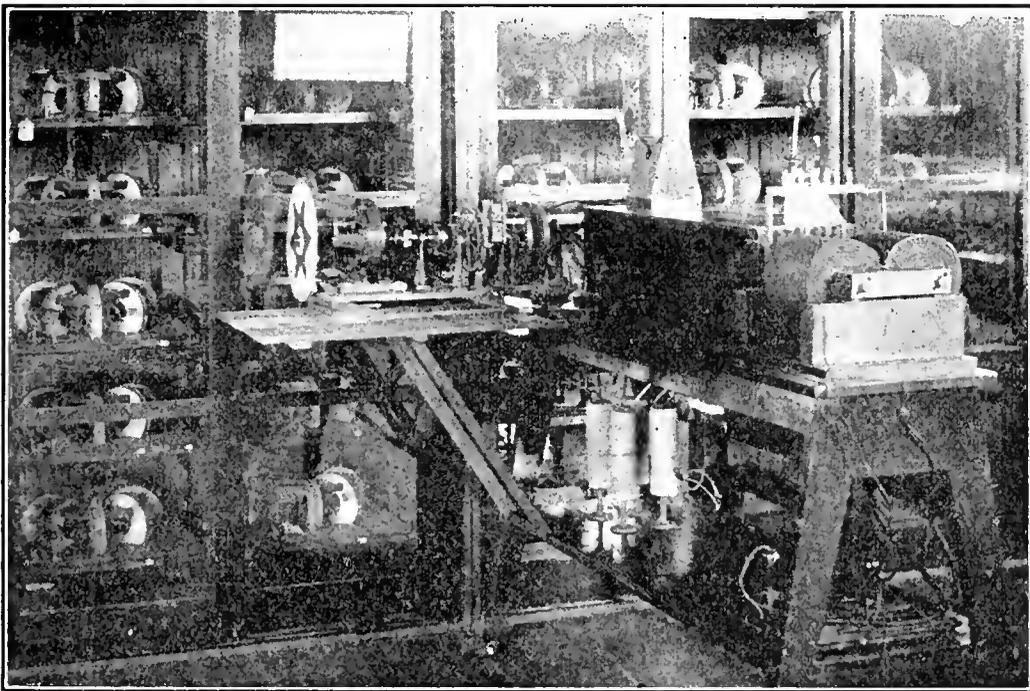
Fig. 8. Artificial Power Transmission Line, Oscillograph and Switching Apparatus.

Case of Regular Transients.—About 150 different triple oscillograms have been secured of initial electromagnetic wave transients, under various conditions, over artificial lines. Only a few of these can be dealt with in this paper.

Fig. 9 (Film No. 40) shows the regular transient case for thirteen half cycles on the full-length artificial line, as defined in Table
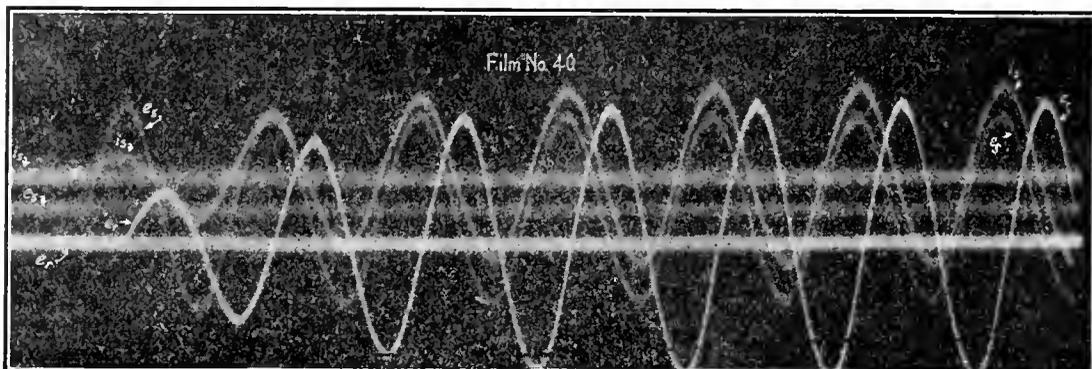
FIG. 9.   Triple Oscillogram of c_s, i_s and c_r for 1255 km. artificial power line freed at distant end. $f = 60.6 \sim$.

II., at the frequency of 60.6 $\sim$, with the distant end free (through the oscillograph at B), and with the line switch closed at or very near to an instant of zero e.m.f. The electrical connections are those of Fig. 3.

The three curves on Film No. 40, Fig. 9, are c_s, i_s and e_r, representing respectively the sending-end e.m.f., the sending-end current and the receiving-end voltage.   The sending-end voltage (76.7 volts r.m.s.) is seen to be substantially uniform throughout the seven cycles.   It may be observed, however, that during the first two or three alterations, the maxima of impressed e.m.f. are slightly higher than those at later stages.   This may have been an effect of throwing on the load.   The same effect could also be detected on a voltmeter, when throwing the line on and off.   In the computations to be subsequently described, these deviations from uniformity in c_s were taken into account.   In the analysis of the oscillographic record, the measured values are all referred, for convenience, to those which, by simple proportion, would be obtained with 100 volts impressed e.m.f.

The i_s curve starts, without appreciable splash, practically in phase with the e.m.f.   Near the end of the first alternation, it is reinforced by a current wave reflection from the distant free end.   These reflections keep coming in, approximately in step with the outgoing alternations, so that the final sending-end current is nearly

six times (5.691) the initial sending-end current. This represents a series of regular initiating a.-c. wave transients.

The e_r curve starts about half an alternation behind the e_s and i_s curves, since 4.3 milliseconds are required to transmit the wave along the artificial line, and an alternation at 60.6 $\sim$ lasts 8.25 milliseconds. It then develops into a sinusoidal wave with an amplitude that steadily increases, owing to increments reflected from the sending end. The steady state is, however, very nearly reached by the end of the oscillogram. The ratio of the final to the initial crest value is 5.627. As has been already mentioned, the line happens to be nearly quarter-wave length for the impressed frequency (60.6 $\sim$).

The growth of the i_s curve and especially of the e_r curve, has been found to be in substantial agreement with the theory of initiating regular transients over the corresponding smooth line, as will shortly be detailed. This means that in spite of the lumpiness of the artificial line, the transient stages of voltage and current development into the a.-c. steady state, are presented substantially as they might be expected over the corresponding smooth line, provided that the voltage application is made at an instant of zero e.m.f.

Splash and Lumpiness Transients Mingled with Regular Initiating Transient.—In Fig. 10 (Film 110), the same artificial line,
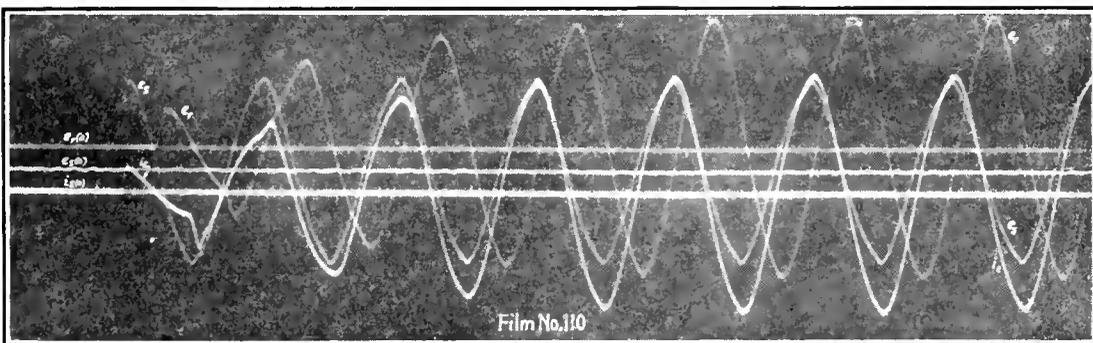
FIG. 10. Example of Splash, Lumpiness and Regular Transients.

freed at the far end, is closed on the same generator at the same frequency. The switch is closed, however, at or near a crest value of impressed e.m.f. e_s. The entering current i_s, instead of rising smoothly, as in Fig. 9, jumps up rapidly to crest value, with an

oscillation in the process, and then descends upon a distorted curve. The deviations from the sinusoidal state are clearly visible in i_s for five alternations, after which the upbuilding progress towards the same final steady state as in Fig. 9, becomes fairly regular. Similarly, the far-end voltage e_r rises with oscillations which are not attributable to the oscillograph, and are probably lumpiness transients. The deviations from the sinusoidal wave form are visible in the growth of e_r for at least four alternations. The case is therefore one of mixed splash, lumpiness, and regular initiating transients. The curves of this case have not been analyzed.

The zero line of e_s contains ripples, which are due to accidental mechanical tremors of the instrument at the moment of zero-line recording. The zero lines were ordinarily recorded after the oscillographic wave records on the line had been secured, and at a time when the instrument was disconnected.

(628 km. or 390 miles) and is grounded at B through a current-
In Fig. 11 (Film No. 106), the artificial line has half length
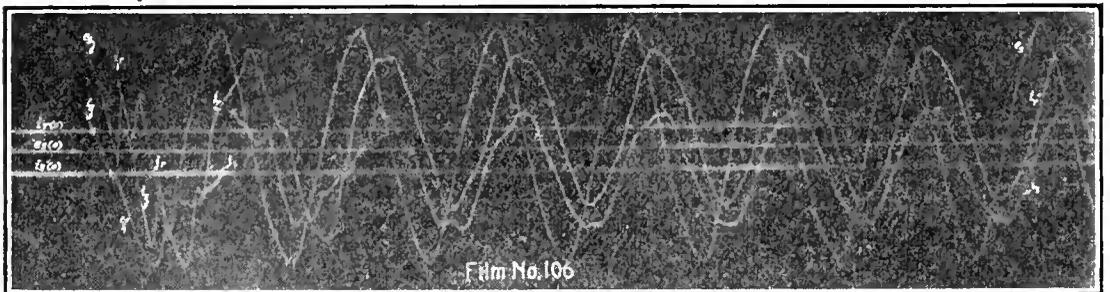
FIG. 11.   Example of Splash, Lumpiness and Regular Transients.

recording oscillograph. The line switch was set to close at or near a crest of impressed e.m.f. of about 70 volts r.m.s. The splash at A is very marked, The curve i_s is the sending-end current, and is very erratic during the first two or three alternations. The receiving-end current i_r is also very erratic, and contains lumpiness oscillation ripples. It slowly regularises itself, as time goes on, towards the steady state. When the line switch was closed at an instant of zero e.m.f., instead of near the crest value, these erratic waves did not present themselves on this 625 km. line. No attempt has been

made to analyze these curves as yet, owing to the bad splash and lumpiness transients they indicate.

Splash Transient Occurring Singly.—If the line is made virtually of infinite length with respect to the sending end, by grounding it at B through an impedance equal to its surge impedance z_0, a splash produced by the closing of the line switch off zero e.m.f., will give rise to a splash transient, that will vanish very quickly at A; because no reflected waves can return from the distant end. An example of this case is presented in Fig. 12 (Film No. 35).
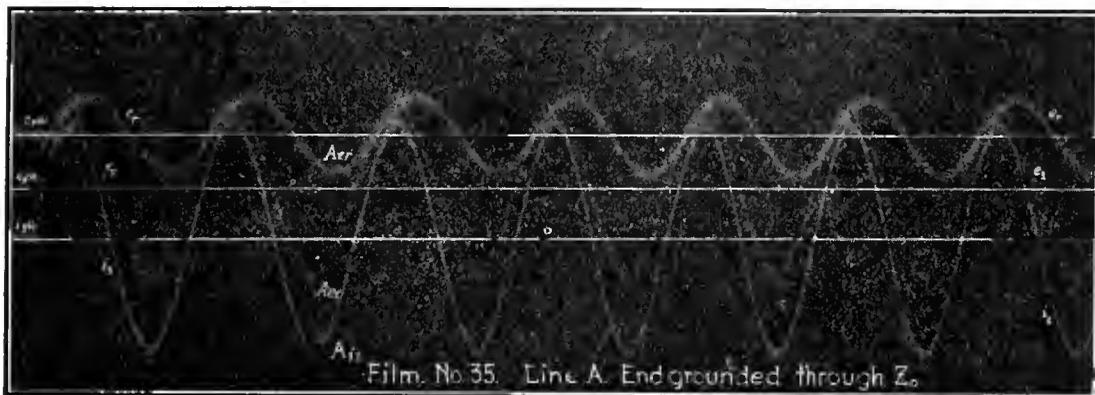
FIG. 12. Non-recurring Splash and Casual Transients.

Approximately the same half-length artificial line as in Fig. 11 (580 km.), is here grounded at B through a combination of resistance and condenser, so as to produce an impedance, at 60.6 $\sim$, of 342.5 $\triangledown$ 4°.4 ohms. The line switch was closed at a phase of about 20 electrical degrees later than the zero of ascending e.m.f. This is seen to produce a splash both in e_s and i_s, the initial outgoing waves of e.m.f. and current. This splash is also seen to be repeated in the B-end voltage e_r, where the load (z_0) is connected. The splash gives rise also to a lumpiness transient, as may be seen by the ripples in i_s, the entering current, during the first alternation. A similar lumpiness ripple transient is faintly perceptible in the first alternation of e_r at B. Neither splash nor lumpiness transients are visible, however, in the second or succeeding alternations in any of the curves, these disturbances, according to theory, being all absorbed at the B end, by the load z_0:

Casual Transients.—At the point Ae_s, Fig. 12, in the fourth

alternation of impressed e.m.f., there is an accidental transient ripple, due to a slip in the contact mechanism of the line-switching apparatus at A. This momentary disturbance is clearly duplicated simultaneously at Ai_s in the sending current. After an interval of about 2 milliseconds, a similar ripple transient appears at Ae_r, in the voltage at B. All of these transients are absorbed in z_0, at B, and do not reappear. Such wave transients may be called *casual transients,* to distinguish them from initiating transients which occur at the starting of an a.-c. regime, or from terminating transients which occur at the opening of an a.-c. circuit.

Regular Transients with Apparent Distortion.—In the case represented by Fig. 9, the e.m.f. and current waves, launched without appreciable splash, develop regular transients that build into the final steady state, without noticeable distortion. The successive alternations increase in size without departing noticeably from their sinusoidal shape. This is for the reason that the successive reflections, so long as they are of appreciable magnitude, happen to make their appearance, at each end of the line, at or near the moments when the voltage and current are passing through zero. This must always happen, according to theory, when the length of the freed line is a quarter wave for the impressed frequency. If, however, the line has a length distinctly different from a quarter wave, or
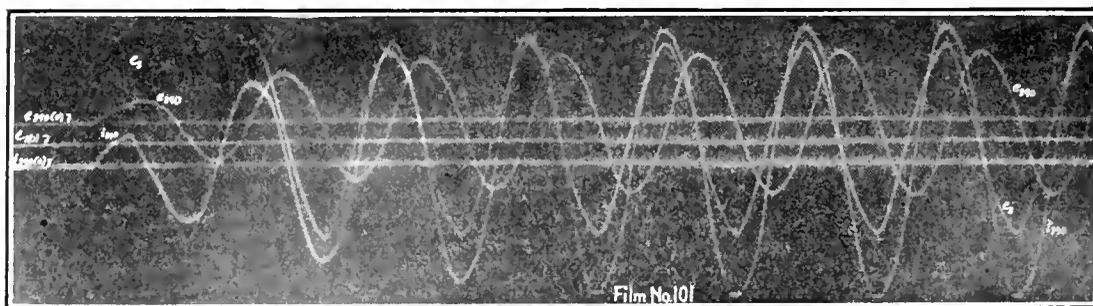
Fig. 13.   Apparent Distortion of Transients due to Interference of Successive Reflections.

simple multiple thereof; or if the voltage and current waves are recorded at some intermediate point of a freed quarter-wave line, each of the successive reflections will come in during the active part of an alternation. In particular cases, they may happen to arrive

at the crests of successive alternations. In such instances, the waves will change abruptly from one sinusoid to another of different amplitude. The resulting waves may therefore appear to be distorted, or nonsinusoidal, until they are analyzed. An example of this kind is presented in Fig. 13 (Film No. 101). Here the full-length artificial line (1255 km.) is freed at the distant end, and the recording oscillographs of e.m.f. and current are connected to the line at the half-way point (627.5 km. from each end). It will be seen that the impressed e.m.f. e_s is applied near an instant of zero voltage, and without perceptible splash. The voltage wave e_{390} at the midlength point, commencing about 2 milliseconds later, rises also without splash, along an approximately sinusoidal curve. Just about the crest of this wave, the first reflection (positive) has had time to return from the distant free end. This reflected wave adds itself to the first arriving wave at the midway point, and so apparently distorts the wave form. These distortions can be noticed for several alternations in e_{390}, and are due almost wholly, if not entirely, to the superposition of new reflections. The same considerations apply to the current i_{390} in the line, at the midway point. The electrical connections are indicated in Fig. 14. The first reflected wave of
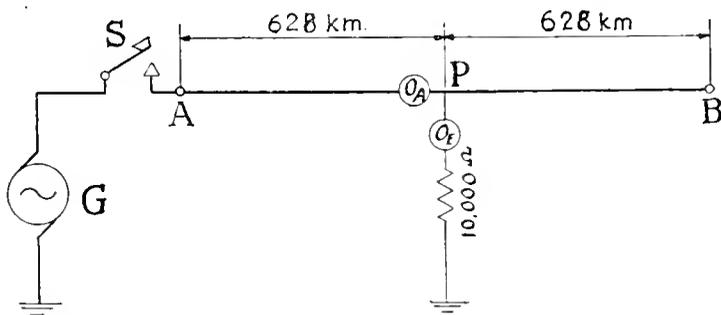
FIG. 14. Electrical Connections of Oscillograph and its Leak, half-way along the Artificial Line freed at B.

current arriving at P, 4.3 milliseconds after the first arrival at P, is in the negative direction from the distant free end B, and so produces a more marked apparent distortion in i_{390}, than occurs in e_{390}, where the first reflection is positive. Similar distortions due to further incoming reflections are noticeable in the curve i_{390} for several alternations. At the end of the oscillogram, 125 milliseconds from the start, the waves of e_{390} and i_{390} have very nearly attained their final steady and practically sinusoidal values.

Analysis of Regular Transient Case.—Fig. 15 presents the theo-
retical stationary vector analysis of the case to which the oscillo-
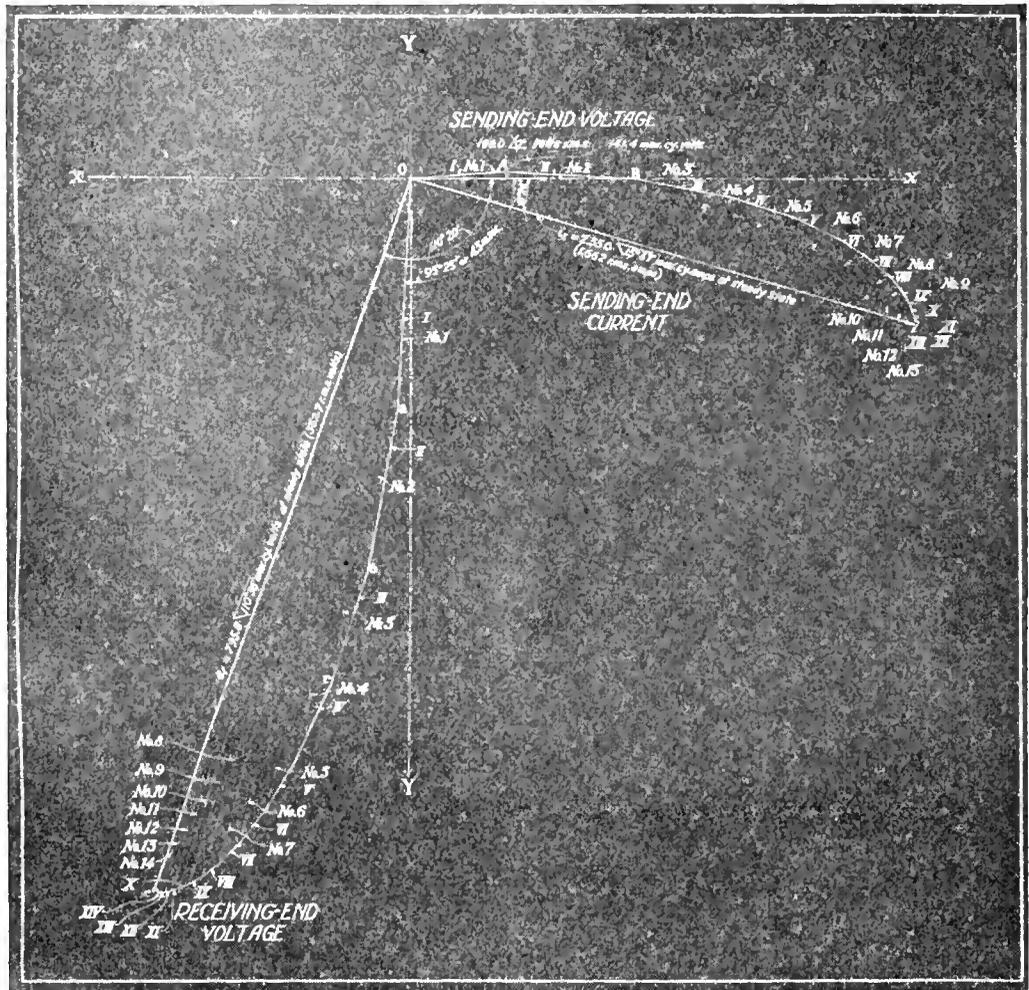
FIG. 15. Vector Diagram of Electromagnetic Terminal Reflections in Long
Distance Power Transmission Line.

gram of Fig. 9 belongs. It is treated in detail in Appendix II.
The axis OX represents the standard phase of the sending end
voltage. The successive maximum cyclic voltage reflections at B,
are represented to scale by the vectors Oa, ab, bc, etc., as far as the
fourteenth inclusive. The vector sum of these (Oa, Ob, Oc, etc.)
are given for each step in the process. Table V. in Appendix II.,
shows the maximum cyclic values attained at each stage. This in-
creases to E_B 796.2 $\triangledown$ 109°.49′ at the thirteenth reflection. After
this, it diminishes slightly to 795.8 $\triangledown$ 110°.36′ in the final steady
state. The final voltage at B is thus 5.63 times the impressed volt-

age at A, owing to the fact that the line AB is nearly of quarter-wave length.[9]

In a similar manner, the successive currents and reflections at A are indicated by the vectors OA, AB, BC, etc., together with the successive vector sums OA, OB, OC, etc., as far as the thirteenth wave inclusive, when the final steady state is nearly reached.

We should therefore expect that the voltage at B would, in the first wave, attain the crest value Oa, in the next reflection the crest value Ob, in the next following reflection Oc, and so on. A comparison between the observed and computed waves is given graphically in Fig. 16. Here the upper line of waves deals with the sending-end current, the middle series with the impressed voltage, and the lowest series with the voltage at B. Referring to the latter series, the successive reflected voltage waves Oa, ab, bc, etc., of Fig. 15, are marked with the numerals I., II., III., etc., in Fig. 16, and these are superposed, by point to point addition, in the heavy wavy line No. 1, No. 2, No. 3, etc. This heavy wave is the computed resultant regular transient of c_r. If there were no errors in the assumptions or mode of computation, the oscillogram of c_r should coincide with this line. The oscillogram of c_r in Fig. 9 actually does coincide very nearly with this theoretical line, the small derivations therefrom being indicated at the crests of the first few waves. Thus, at the crest of wave No. 3, the computed maximum value is 531.9 volts; whereas the oscillograph shows 539 volts, a deviation of 1.3 per cent. This is the largest discrepancy detected between the observed and computed values of c_r. We are, therefore, entitled to conclude that in the case of this artificial line, with the switch closed splashlessly, the lumpiness of the line had very little effect upon the voltage at the distant free end.

Referring to the upper line of waves i_s in Fig. 16, the same procedure has been followed. The heavy line is the sum of the reflected waves, according to the vector sums OA, OB, OC, of Fig. 15. This heavy wavy line is, therefore, the theoretical summation

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[9] If the line had been freed at B, instead of being grounded through the oscillograph of 9900 ohms, the final voltage E at B would have been increased from $E \times 5.63 \angle 110° 36'$ to $E \times 6.82 \angle 116° 20'$, and the transient e.m.f. waves would also have been materially modified.
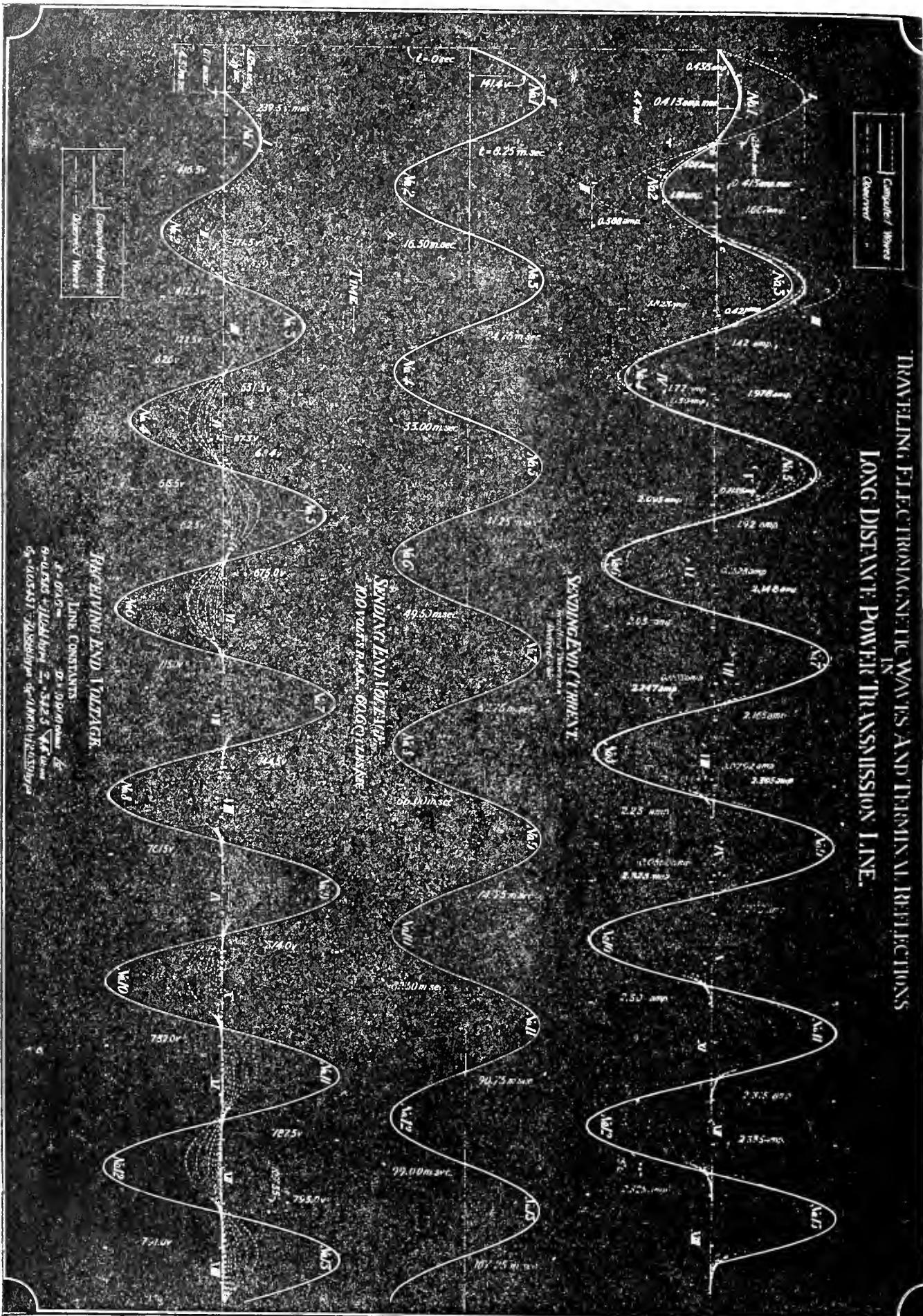
FIG. 16.

of regular current transients at A. The oscillogram of i_s should coincide with this line, if there were no errors in assumptions or computation. The actual oscillographed i_s wave is shown by a chain line in Fig. 16, and the deviations of this from the heavy line are marked thereon at the successive crests. It will be seen that, in the first wave, the discrepancy is small. The discrepancy increases up to wave No. 3, when it reaches 17.5 per cent. The discrepancy then dies away, almost to zero, in the last wave, No. 13.

This discrepancy in current amplitude, reaching a maximum at the third wave, is too large to be attributable to errors of interpretation in the oscillogram. It may be attributed therefore either to

(1) small higher harmonics in the wave of impressed e.m.f.; *i.e.*, to deviation from the sinusoidal form, with initial wave transients resulting therefrom,

(2) imperfect regulation of impressed e.m.f., or initial deviation of e_s from the normal amplitude, with initiating wave transients resulting therefrom,

(3) lumpiness in the artificial line, with corresponding initiating wave transients,

(4) secondary reflections at A from the internal impedance of the alternator, not taken into account.

The shares of the above possible sources of discrepancy in i_s have not been determined. It is intended, however, to substitute a tapering pair of smaller π sections, for the first section at the A end of the line, so as to diminish the lumpiness of the line at the generating end, where the waves start. Ordinarily, the greatest discrepancies between theory and observation are to be expected in the initiating wave transients of current at the sending end. All errors are exaggerated at this point. Considering the complexity of the conditions, it is remarkable that the discrepancies have not been larger.

Of the considerable number of initiating wave transient oscillograms which have been obtained on this and other artificial lines, Fig. 9 is a fair sample, and not a specially selected case. It has been analyzed to a greater extent, however, than any of the rest. The conclusion to be drawn from this analysis seems to be sup-

ported by other cases, so far as they have been examined; namely, that at the impressed frequency of 60 $\sim$, nearly sinusoidal, if the voltage is impressed without splash at an instant of zero e.m.f., the artificial line behaves substantially like its conjugate smooth line, the greatest discrepancy being in the current-wave transient at the sending end. Consequently, any similar artificial line of a like degree of lumpiness, should be available, in the laboratory, for the study of initiating and casual a.-c. wave transients.

Arrival Times.—The apparent velocity of transmission of an a.-c. wave over an artificial line subtending an angle of $\theta = \theta_1 + j\theta_2$ hyps radians $\angle$, at a given impressed frequency $f \sim$ is[10]

$$v = \frac{L\omega}{\theta_2} \qquad \frac{\text{km.}}{\text{sec.}}, \quad (4)$$

where L is the length of the line in kilometers. This velocity is the "group velocity" of the waves at this frequency. For the artificial line considered, at 60.6 $\sim$, $v = 292,300$ km./sec. It tends to reach the limit 300,000 km./sec. at very high frequencies, in air.

The number of single passages, or single transits, of the wave over the line per second, is

$$n = \frac{v}{L} = \frac{\omega}{\theta_2} \qquad \frac{\text{numeric}}{\text{sec.}}. \quad (5)$$

In the case of this line at 60.6 $\sim$, $n = 232.9$ transits per second. The transit time T, or time interval of a single passage over the line, from one end to the other, is*

$$T = \frac{1}{n} = \frac{\theta_2}{\omega} \qquad \text{seconds.} \quad (6)$$

In the case to which Fig. 9 refers, $\theta_2 = 1.041$ quadrants, and $\omega = 60.6 \times 4 = 242.4$ quadrants per second. Hence, $T = 0.004295$ second, or nearly 4.3 milliseconds. At a point P, whose angular distance from the ends A and B are $\theta' = \theta_1' + j\theta_2'$ and $\theta'' = \theta_1''$

[10] Bibliography 30, p. 283.

* Bibliography 30, p. 283.

$+ j\theta_2''$ hyps respectively, the *arrival time*, or time of transit from A to P is

$$T_1 = \frac{\theta_2'}{\omega} \qquad\qquad \text{seconds.} \quad (7)$$

The time required for the wave to go from A past P to B, and back to P, thus making one reflection from the distant end, will be

$$T_{P1} = \frac{\theta_2' + 2\theta_2''}{\omega} = \frac{2\theta_2 - \theta_2'}{\omega} = 2T - T_1 \quad \text{seconds.} \quad (8)$$

This interval may be called the B *reflection* time at the point P.

The second B reflection at P arrives after a time T_{P2} from switch closure

$$T_{P2} = 2T + T_{P1} = \frac{4\theta_2 - \theta_2'}{\omega} = 4T - T_1 \quad \text{seconds.} \quad (9)$$

Similarly, the kth arrival at P occurs after a time from switch closure of

$$2(k - 1)T + T_1 = \frac{2(k - 1)\theta_2 + \theta_2'}{\omega} \quad \text{seconds.} \quad (10)$$

Again, the kth reflection from the B end reaches P after a time T_{PK} from switch closure.

$$T_{Pk} = 2(k - 1)T + T_{P1} = \frac{2k\theta_2 - \theta_2'}{\omega} = 2kT - T_1 \quad \text{seconds.} \quad (11)$$

In the case when P is situated at B, as in the example of Fig. 9, $\theta' = \theta$, $\theta'' = 0$, so that

$$T_{B1} = \frac{\theta_2}{\omega} = T \qquad\qquad \text{seconds.} \quad (12)$$

and

$$T_{Bk} = 2(k - 1)T + T = (2k - 1)T \quad \text{seconds.} \quad (13)$$

Instantaneous Value of Growth Factor.—If a sinusoidal e.m.f. of E_A max. cyclic volts, at standard phase, is impressed on the A end of the line at an instant of zero voltage, then the instantaneous

value at A, t seconds after switch closing, will be

$$e_A = E_A \sin \omega t \qquad \text{volts.} \quad (14)$$

As shown in Appendix I., the vector voltage at P in the final steady state will be[11]

$$E_{P\alpha} = E_A \frac{\sinh \delta_P}{\sinh \delta_A} \quad \text{max. cy. volts.} \angle. \quad (15)$$

The size of $E_{P\infty}$ is the size of this planevector quantity, and may be represented by $|E_{P\infty}|$. If its slope is $-\beta°$, then the instantaneous value at P in the steady state, after t seconds, is

$$P_{P\alpha} = |E_{P\alpha}| \sin (\omega t - \beta^0) \qquad \text{inst. volts.} \quad (16)$$

It is also shown in Appendix I. that at P, after the passage of the kth reflection from B, and before the arrival of the $(k+1)$th reflection from A, the max. cyclic vector voltage is

$$E_{Pk} = E_{P\alpha} (1 - \epsilon^{-2k\delta_A}) = E_{P\alpha} \cdot 2\epsilon^{-k\delta_A} \sinh k\delta_A \quad \text{max. cy. volts.} \angle. \quad (17)$$

If the size of this planevector quantity be denoted by $|E_{Pk}|$, and its slope is $-\beta_k°$; then at any time t between the kth and $(k+1)$th reflections, the instantaneous e.m.f. at P will be

$$e_{Pk} = |E_{Pk}| \sin (\omega t - \beta_k^0) \qquad \text{inst. volts.} \quad (18)$$

The slope $-\beta_k°$ changes abruptly at each succeeding increment.

Graphical Development of Initiating Transients.—A rotatory vector diagram of the voltage developed at the B end of the line in the case represented by Fig. 3, is indicated in Fig. 17, for the first four reflections. The line $-XOX$ is the projection axis. Projections on this axis from a rotating vector e.m.f. indicate the instantaneous e.m.f. at the end B of the line, with the oscillograph load of 9900 ohms.

The vector OA represents the first reflected wave of 239.5 max. cy. volts at B, at the instant of its arrival there, and when its instantaneous value is still zero. This vector OA then rotates

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[11] Bibliography 30.

counterlockwise at the angular velocity of the impressed e.m.f.; *i.e.*, 60.6 revolutions per second. Its projection on the line OX at any instant t seconds after arrival, will then give the instantaneous e.m.f.
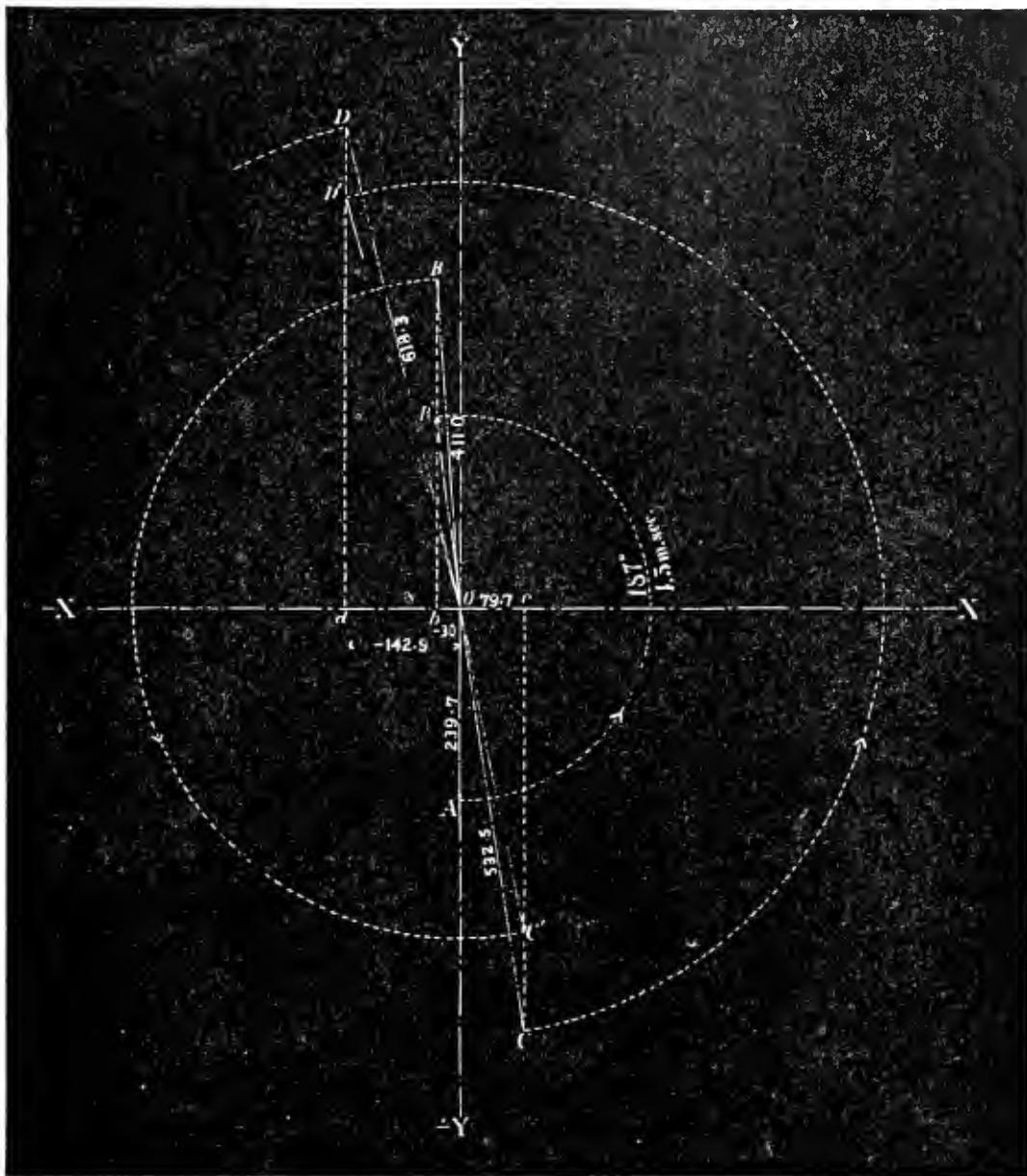
FIG. 17. Rotary Vector Diagram of e.m.f. at B during part of Transient Period.

at B. When the vector OA has described $187°$, and reached the position OB' with an instantaneous value of $Ob = -30.0$ volts, 8.6 milliseconds later than the position OA, the second reflected wave arrives. The resultant of OA and the second reflection has a

size equal to that of OB, as obtained by consulting the stationary vector diagram Fig. 15. OB is now the new rotating vector, but its projection on OX must commence at the same value Ob as existed at the instant of the second reflection's arrival. This requires an instantaneous leap of the projecting vector from OB' to OB. The new vector OB now executes the half circle BC' (187°) at the standard angular velocity, until it reaches the position OC', 8.6 milliseconds later than that it occupied at OB. Here the third reflection arrives and requires an instantaneous change of the vector from OC' to OC, with a common instantaneous projection Oc. The new resultant vector OC, of three reflections, now rotates through 187° to OD', when the fourth reflection arrives and causes an immediate change to OD. This process goes on indefinitely. It will be observed that although Fig. 17 represents the instantaneous e.m.f. at the receiving end of the line from the moment of arrival of the first reflection, the angular position of the rotating vector ceases to correspond to the time which has elapsed, owing to the instantaneous backward leaps at the moments when new reflections arrive.

It may be observed that, referring to Fig. 15, the envelope of the successive resultants of e.m.f. reflections $Oa, b, c,$ etc., is an equiangular spiral. The same is true for the corresponding envelope of current-wave reflections, as laid down in a stationary vector diagram $O\ A\ B\ C$, etc., Fig. 15. When the successive waves of arrival and reflection are summed at a point P along the line, instead of at the distant end B, the same propositions will be found to apply to the envelope of the successive reflections. The vectors of arriving waves will, however, differ, in general, from those of the reflections succeeding them.

The algebraic expression corresponding to Fig. 17 is:

$$e_B = E_{Am}\{m\epsilon^{-\theta_1}\sin(\omega t - \theta_2) + m(1 - m)\epsilon^{-3\theta_1}\sin(\omega t - 3\theta_2)$$
$$+ m(1 - m)^2\epsilon^{-5\theta_1}\sin(\omega t - 5\theta_2) + \cdots\}\quad\text{inst. volts.}\quad(18a)$$

Here each term must be included after the time has elapsed for its arrival. Three phase angles present themselves in each term;

namely, (1) the phase angle ωt, which increases uniformly with t, the time elapsed from switch closure; (2) the angle θ_2, $3\theta_2$, $5\theta_2$, etc., which is a multiple of the circular angle θ_2 subtended by the line, and is the phase delay due to 1, 3, 5, etc., wave passages over the line; (3) the slope of the vector coefficient m, $m(1-m)$, etc., which takes into account the change of phase in the voltage wave due to reflections. The scalar sum of the terms in $(18a)$ agrees at any instant with the projection on OX in Fig. 17.

Summary.

1. Oscillographic measurements over a lumpy artificial power-transmission line in the laboratory, are reported for certain initiating wave transients. The technique is described. One of these oscillographs is analyzed, and compared with the elementary theory of steady-state attainment. The discrepancies between the observed and computed values are negligible for the voltage waves at the receiving end of the line. They are distinct, but not very serious, for the outgoing current waves at the sending end.

2. A lumpy artificial line can be used for the measurement of initiating a.-c. wave transients, if an automatic circuit-closing switch is set to connect the generator to the line at a moment of zero e.m.f.

3. A provisional classification of transients is offered. Particular cases of splash transients, lumpiness transients, casual transients, and regular initiating transients are offered, from experimental observations.

4. The growth factor of a regular series of transients is analyzed for any point P in a single line loaded at the receiving end. This growth is a discontinuous function of time, its increase occurring by little vector jumps. The envelope of the growth-factor vector is an equiangular spiral. The growth factors for current and voltage are the same.

5. The transitory impedance at and beyond any one point on a line such as is described, is constant at successive B reflections, after the first reflection from B, and is equal to the impedance at that point in the final steady state.

6. The position angle of the B end of a loaded line in the steady

state is directly related to the transient transmission and reflection coefficients, at that end, during the preliminary state.

7. The process of transmitting power along an alternating-current line may be simply conceived of as the rate of delivery, at the sending end, of magnetic and electric fluxes, with their necessarily contained energies.

APPENDIX I.

On the Regular Attenuation of Sinusoidal Waves over a Smooth Uniform Line Loaded with an Impedance at the Receiving End.

In Fig. 3, let the smooth uniform line AB be voltaged at A and loaded at B with an impedance σ vector ohms (or ohms $\angle$). The switch is closed at A without splash, on a single-frequency alternator of negligible internal impedance and frequency $f \sim$, generating 1 volt maximum cyclic e.m.f. The line has a total conductor impedance $Z = R + jL\omega$ ohms $\angle$, and a total dielectric admittance of $Y = G + jC\omega$ mhos $\angle$, where

$R =$ total conductor resistance (ohms),
$L =$ total conductor inductance (henrys),
$G =$ total dielectric conductance (mhos),
$C =$ total dielectric capacitance (farads),
$\omega = 2\pi f$ (radians per sec.).

Required the development with time of voltage and current at the arbitrary point P, distant θ' hyps $\angle$ from A, and θ'' hyps $\angle$ from B, the total angle subtended by the line AB being

$$\theta = \theta' + \theta'' = \sqrt{ZY} = \theta_1 + j\theta_2 \qquad \text{hyps } \angle. \quad (19)$$

The surge impedance of the line is

$$\varsigma_0 = \sqrt{\frac{Z}{Y}} \qquad \text{(ohms } \angle\text{).} \quad (20)$$

E.m.f. Waves or Electrostatic Flux Waves.—The initial outgoing wave of e.m.f. at A, when $t = 0$, is represented by a vector

of $1.0 \angle 0°$ volt max. cyclic value. After this wave of e.m.f. has reached P, it will have attenuated to the vector perunitage

$$\epsilon^{-\theta'} = \epsilon^{-(\theta_1' + j\theta_2')} = \epsilon^{-\theta_1'} \times \epsilon^{-j\theta_2'} = \epsilon^{-\theta_1'} \triangledown \theta_2' \qquad \text{numeric } \angle . \quad (21)$$

where θ_2' is expressed in real circular radians (or imaginary hyperbolic radians), lagging in phase behind the generator e.m.f. at that moment. When the wave has reached B, the receiving end of the line, its condition will be $\epsilon^{-} = \epsilon^{-\theta_1} \triangledown \theta_2$. At the junction BC, the wave breaks into a transmitted and reflected component. If the transmission coefficient is m, then, following in planevector notation what Heaviside[12] first showed, with real numbers only, for the distortionless case:

$$m = \frac{\sigma}{\dfrac{z_0 + \sigma}{2}} = \frac{2\sigma}{z_0 + \sigma} \qquad \text{numeric } \angle, \quad (22)$$

and the e.m.f. transmitted to σ at C is $m\epsilon^{-\theta}$ \qquad volts $\angle$. (23)

The voltage for reflection at B will be $(1 - m)^{-\theta}$ volts. This voltage is directed back from B towards A, and should be counted as $-(1 - m)\epsilon^{-\theta} = (m - 1)\epsilon^{-\theta}$ volts $\angle$ on the line.

The time required for the wave to reach P from A will be θ_2'/ω seconds, and to reach B, θ_2/ω seconds. This is the traverse time of the line and may be denoted by T. We may therefore represent the progress of the wave by the following table. The assumption is made as a first approximation, that the generator at A has negligible internal impedance; i.e., that the effect of its internal e.m.f., acting in conjunction with reflections from its actual internal impedance, is the same as its terminal e.m.f. steadily impressed at A would have with zero internal impedance (Table III.). Here δ_B is the position angle at the end B of the line in the steady state or $\tanh^{-1}(\sigma/z_0)$. Again $\delta_A = \theta + \delta_B$ is the position angle at the end A of the line in the steady state. Also $\delta_P = \theta'' + \delta_B = \delta_A - \theta'$ is the position angle at the selected point P of the line in the steady state. It is well known that, in the steady state, if the impressed voltage at A is $1.0 \angle 0°$ max. cy. volts, the final voltage at P is $(\sinh \delta_P)/(\sinh \delta_A)$.

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[12] Bibliography 1.

TABLE III.

Schedule of Voltage Wave Arrivals and Reflections at a Point P on a Uniform Line AB, on which Unit Max. Cy. E.M.F. is Impressed at A, and a Load σ Vector Ohms is Connected at B.

No. of Wave.	Time at A. t Secs.	A.	P.	B.	C.	Time at C. t Secs.
1A	o	1.0	$\epsilon^{-\theta'}$	$\epsilon^{-\theta}$	$m\epsilon^{-\theta}$	T
1R	$2T$	$(m-1)\epsilon^{-2\theta}$	$(m-1)\epsilon^{-(2\theta-\theta')}$	$(m-1)\epsilon^{-\theta}$		T
2A	$2T$	$(1-m)\epsilon^{-2\theta}$	$(1-m)\epsilon^{-(2\theta+\theta')}$	$(1-m)\epsilon^{-3\theta}$	$m(1-m)\epsilon^{-3\theta}$	$3T$
2R	$4T$	$-(m-1)^2\epsilon^{-4\theta}$	$-(m-1)^2\epsilon^{-(4\theta-\theta')}$	$-(m-1)^2\epsilon^{-3\theta}$		$3T$
3A	$4T$	$(1-m)^2\epsilon^{-4\theta}$	$(1-m)^2\epsilon^{-(4\theta+\theta')}$	$(1-m)^2\epsilon^{-5\theta}$	$m(1-m)^2\epsilon^{-5\theta}$	$5T$
3R	$6T$	$(m-1)^3\epsilon^{-6\theta}$	$(m-1)^3\epsilon^{-(6\theta-\theta')}$	$(m-1)^3\epsilon^{-5\theta}$		$5T$
$\cdots$	$\cdots$	$\cdots$	$\cdots$		$\cdots$	$\cdots$
kA	$2(k-1)T$	$(1-m)^{k-1}\epsilon^{-2\theta(k-1)}$ $=\epsilon^{-2(k-1)\delta_A}$	$(1-m)^{k-1}\epsilon^{-\{2(k-1)\theta+\theta'\}}$ $=\epsilon^{-2(k-1)\delta_A+\theta'}$	$(1-m)^{k-1}\epsilon^{-(2k-1)\theta}$ $=\epsilon^{-(2k-1)\delta_A+\delta_B}$	$m(1-m)^{k-1}\epsilon^{-(2k-1)\theta}$	$(2k-1)T$
kR	$2kT$	$-(1-m)^k\epsilon^{-2k\theta}$ $=-\epsilon^{-2k\delta_A}$	$-(1-m)^k\epsilon^{-(2k\theta-\theta')}$ $=-\epsilon^{-(2k\delta_A-\theta')}$	$-(1-m)^k\epsilon^{-(2k-1)\theta}$ $=-\epsilon^{-(2k-1)\delta_A-\delta_B}$	$2\sinh\delta_B\,\epsilon^{-(2k-1)\delta_A}$	"
Sum to	$2kT$	1.0	$\dfrac{\sinh\delta_P}{\sinh\delta_A}(1-\epsilon^{-2k\delta_A})$	$\dfrac{\sinh\delta_B}{\sinh\delta_A}(1-\epsilon^{-2k\delta_A})$		Sum to $2(k-1)T$
" "	"	1.0	$\sinh\delta_P\cdot 2\epsilon^{-k\delta_A}\sinh k\delta_A$	$\sinh\delta_B\cdot 2\epsilon^{-k\delta_A}\sinh k\delta_A$		"
" "	"	1.0	$E_{P\alpha}\cdot 2\epsilon^{-k\delta_A}\sinh k\delta_A$	$E_{B\alpha}\cdot 2\epsilon^{-k\delta_A}\sinh k\delta_A$		"

Consequently, if instead of taking the final voltage at P in the steady state, we take the stage of voltage growth at P found after k reflections from B have passed P, the corresponding vector stage of E_P, which may be denoted by E_{Pk}, is

$$E_{Pk} = E_{P\infty}(1 - \epsilon^{-2k\delta_A}) = E_{P\infty}(2\epsilon^{-k\delta_A}\sinh k\delta_A) \quad \text{volts} \angle . \quad (24)$$

The vector coefficient within the brackets may be described as the vector coefficient of growth, k being an integer, increasing by unit steps. At $k = \infty$, this coefficient reaches unity. It is a real coefficient, or has no imaginary component, when the imaginary part of δ_A is a quadrant or any integral number of quadrants. Thus, if the line with its load at B develops a quarter-wave length at A; so that δ_A contains one imaginary quadrant, then $\epsilon^{-2k\delta_A}$ is a real number, and so is the coefficient of growth at all stages. The phase of the final voltage at P will then be the same as that at the arrival of the first wave.

Current Waves or Magnetic Flux Waves.—If the e.m.f. impressed on A is $1.0 \angle 0°$ max. cy. volts, without splash, the initial outgoing current at A is $1 \angle 0°/z_0 = E_A y_0 = I_0$ amperes $\angle$, where y_0 is the surge admittance $1/z_0$. The first current wave arrival at P finds this attenuated to $I_0 \epsilon^{-\theta'}$ and the first arrival at B to $I_0 \epsilon^-$ vector amperes. In each successive arrival, the value I_0 appears, and in tabulating the wave progress, I_0 may be omitted as a common multiplier throughout, until the summation is effected. We may therefore prepare a schedule of reflections similar to that given for the waves of e.m.f. The coefficients of transmission and reflection of the current waves arriving at B are however different from those for the voltage waves. The coefficient of current-wave transmission n is

$$n = \frac{z_0}{\left(\dfrac{z_0 + \sigma}{2}\right)} = \frac{2z}{z_0 + \sigma} \quad \text{numeric} \angle \quad (25)$$

and the reflection coefficient is

$$n - 1 = \frac{z_0 - \sigma}{z_0 + \sigma} \quad \text{numeric} \angle, \quad (26)$$

TABLE IV.

Schedule of Current Wave Arrivals and Reflections at a Point P on a Uniform Line AB, on which a Current of Max. Cy. Strength $I_0 = E/Z_0$ Vector Amperes is Launched at A, and to which a Load of σ Vector Ohms is Connected at B.

No. of Wave.	Time at A, t Secs.	A.	P.	B.	C.	Time at C, t Secs.
1A	0	1.0	$\epsilon^{-\theta'}$	$\epsilon^{-\theta}$		T
1R					$n\epsilon^{-\theta}$	T
2A	2T	$(n-1)\epsilon^{-2\theta}$	$(n-1)\epsilon^{-(2\theta-\theta')}$	$(n-1)\epsilon^{-\theta}$		$3T$
	2T	$(n-1)\epsilon^{-2\theta}$	$(n-1)\epsilon^{-(2\theta+\theta')}$	$(n-1)\epsilon^{-3\theta}$	$n(n-1)\epsilon^{-3\theta}$	$3T$
2R / 3A	4T	$(n-1)^2\epsilon^{-4\theta}$	$(n-1)^2\epsilon^{-(4\theta-\theta')}$	$(n-1)^2\epsilon^{-3\theta}$		$5T$
	4T	$(n-1)^2\epsilon^{-4\theta}$	$(n-1)^2\epsilon^{-(4\theta+\theta')}$	$(n-1)^2\epsilon^{-5\theta}$	$n(n-1)^2\epsilon^{-5\theta}$	$5T$
3R	6T	$(n-1)^3\epsilon^{-6\theta}$	$(n-1)^3\epsilon^{-(6\theta-\theta')}$	$(n-1)^3\epsilon^{-5\theta}$		
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
kA	$2(k-1)T$	$(n-1)^{k-1}\epsilon^{-2(k-1)\theta} = \epsilon^{-2(k-1)\delta_A}$	$(n-1)^{k-1}\epsilon^{-\{2(k-1)\theta+\theta'\}} = \epsilon^{-2(k-1)\delta_A+1+\theta'}$	$(n-1)^{k-1}\epsilon^{-(2k-1)\theta} = \epsilon^{-2(k-1)\delta_A-\theta}$	$n(n-1)^{k-1}\epsilon^{-(2k-1)\theta} = 2\cosh\delta_B\,\epsilon^{-(2k-1)\delta_A}$	$(2k-1)T$
kR	$2kT$	$(n-1)^k\epsilon^{-2k\theta} = \epsilon^{-2k\delta_A}$	$(n-1)^k\epsilon^{-(2k\theta-\theta')} = \epsilon^{-(2k\delta_A-\theta')}$	$(n-1)^k\epsilon^{-(2k-1)\theta} = \epsilon^{-(2k-1)\theta}$		$(2k-1)T$
Sum to	$2kT$	$I_0\dfrac{\cosh\delta_A}{\sinh\delta_A}(1-\epsilon^{-2k\delta_A})$	$I_0\dfrac{\cosh\delta_P}{\sinh\delta_A}(1-\epsilon^{-2k\delta_A})$	$I_0\dfrac{\cosh\delta_B}{\sinh\delta_A}(1-\epsilon^{-2k\delta_A})$		Sum to $2(k-1)T$
" "	..	$I_A\dfrac{\cosh\delta_A}{\cosh\delta_A}(1-\epsilon^{-2k\delta_A})$	$I_A\dfrac{\cosh\delta_P}{\cosh\delta_A}(1-\epsilon^{-2k\delta_A})$	$I_A\dfrac{\cosh\delta_B}{\cosh\delta_A}(1-\epsilon^{-2k\delta_A})$		..
" "	..	$I_A\alpha(1-\epsilon^{-2k\delta_A})$	$I_P\alpha(1-\epsilon^{-2k\delta_A})$	$I_B\alpha(1-\epsilon^{-2k\delta_A})$		..
" "	..	$I_A\alpha\cdot2\epsilon^{-2k\delta_A}\sinh k\delta_A$	$I_P\alpha\cdot2\epsilon^{-k\delta_A}\sinh k\delta_A$	$I_B\alpha\cdot2\epsilon^{-k\delta_A}\sinh k\delta_A$		
including $(k+1)A$	$2kT$	$I_A\alpha(1-\epsilon^{-2k\delta_A}) + I_0\epsilon^{-2k\delta_A}$				

so that in terms of m,

$$n = 2 - m \qquad \text{numeric} \angle \qquad (27)$$

and

$$n - 1 = 1 - m \qquad \text{numeric} \angle \qquad (28)$$

These rules are of general application, and may be thus expressed. The sum of the voltage and current transmission coefficients at a junction point in a line is equal to 2. The two reflection coefficients have the same size, but have mutually opposite signs.

APPENDIX II.

On the Case of Line AB Connected as in Fig. 1, and Oscillographed as in Fig. 9 (Film No. 40), with 100 Volts R.m.s. Sinusoidal, Impressed at A, with Negligible Splash and Negligible Lumpiness Transient.

Taking the tabulated constants of the artificial line from Table II., the impedance of the oscillograph load at B was $\sigma = 9900 \angle 0°$ ohms. The angle δ_B subtended by this load

$$= \tanh^{-1} \frac{9900 \angle 0°}{342.5 \diagdown 4° 24'} = 0.03451 + j0.9983 \text{ hyp.}$$

This is the position angle δ_B of the end B of the line in the steady state. The position angle of the A end is $\delta_A = \theta + \delta_B = 0.1660 + j2.0393$ hyps.

The e.m.f. at B in the final steady state with $141.4 \angle 0°$ max. cyclic volts at A will be

$$E_B = 141.4 \angle 0° \times \frac{\sinh (0.03451 + j0.9983)}{\sinh (0.1660 + j2.0393)} = 795.8 \diagdown 110° 36' \text{volts.}$$

Similarly, the sending-end final current at A in the steady state is

$$I_S = \frac{E_A}{z_0 \tanh \delta_A} = \frac{141.4 \angle 0°}{342.5 \diagdown 4° 24' \times 0.17571 \angle 20° 0' 45''}$$

$$= \frac{141.4 \angle 0°}{60.180 \angle 15° 36' 45''} = 2.350 \diagdown 15° 36' 45'' \text{ amperes.}$$

Comparing these values with those taken from the oscillograph Fig. 9, $E_r = 796 \,\triangledown\, 110°$ max. cyclic volts, and $I_s = 2.35 \,\triangledown\, 15°$ max. cy. amperes. This agreement is satisfactory, and is even closer than the interpretation of the oscillograph record would warrant. The width of the curves in Fig. 9 is greater than in subsequent oscillographs, when the optical technique had been improved; so that the precision of measurement in Fig. 9 is somewhat below that later attained.

It is shown in Appendix I, that with a given load of σ vector ohms, applied at B to a single smooth line, with a sinewave of unit maximum e.m.f. applied splashlessly at A, the voltage wave at a point P on the kth reflection from the B end, is

$$- (1 - m)^k \epsilon^{-(2k\theta - \theta')} \quad \text{max. cy. volts } \angle, \quad (29)$$

where m is the transmission coefficient to a voltage wave arriving at B, θ is the angle subtended by the line, and θ' the angle from A to the selected point P. This expresses both the size and slope of the kth return wave at P, with respect to unity size and zero slope, or standard voltage phase, at A.

The summation of all the e.m.f. waves arriving at the point P, including the kth reflected wave from B, is also shown to be

$$\frac{\sinh \delta_P}{\sinh \delta_A}(1 - \epsilon^{-2k\delta_A}) = \frac{\sinh \delta_P}{\sinh \delta_A} \cdot 2\epsilon^{-k\delta_A} \sinh k\delta_A \quad \text{max. cy. volts } \angle. \quad (30)$$

But the final steady voltage at P is $(\sinh \delta_P)/(\sinh \delta_A)$ volts $\angle$; so that the summation to the kth return wave at P, inclusive, is equal to the final voltage multiplied by the vector "growth coefficient"

$$w = 1 - \epsilon^{-2k\delta_A} = 2\epsilon^{-k\delta_A} \sinh k\delta_A \quad \text{numeric } \angle. \quad (31)$$

If, then. we denote the final max. cyclic voltage at P by $E_{P\infty}$ vector volts, the corresponding maximum cyclic voltage at an intermediate period, after the arrival of the kth return wave from B, and before the arrival of the next following incoming wave from A, is

$$E_{Pk} = E_{P\alpha} \cdot w \quad \text{max. cy. volts } \angle. \quad (32)$$

The growth coefficient w is not a continuous function of time. It increases by a sudden jump at each moment when a new reflected wave arrives. The size of w is zero up to the time when $k = 1$, and attains unity when $k = \infty$, but it may exceed unity during the process of increase. That is, the max. cyclic voltage E_{Pk} may happen to be greater at some stage of the regular transient state, than in the final steady state. The slope of w may also vary over a considerable range during the period of regular transient growth.

Similarly, referring to Appendix I., Table IV. shows that the attenuation coefficient of the current wave at a point P on the kth reflection from the B end of the line is

$$(n - 1)^k \epsilon^{-(2k\theta - \theta')} = \epsilon^{-(2k\delta_A - \theta')} \qquad \text{numeric } \angle, \quad (33)$$

where n is the transmission coefficient of a current wave arriving at B. The summation of all the current waves arriving at the point P, including the kth reflected wave from B, is also shown to be

$$I_{Pk} = I_A \frac{\cosh \delta_P}{\cosh \delta_A} \left(1 - \epsilon^{-2k\delta_A} \right)$$

$$= I_A \frac{\cosh \delta_P}{\cosh \delta_A} \cdot 2\epsilon^{-k\delta_A} \sinh k\delta_A \qquad \text{max. cy. amperes } \angle, \quad (34)$$

where I_A is the max. cy. current at A in the steady state, ordinarily taken to E_A as standard phase.

But the max. cyclic current at P in the steady state is known to be

$$I_{P\alpha} = I_A \cdot \frac{\cosh \delta_P}{\cosh \delta_A} = \frac{E_A}{z_0} \cdot \frac{\cosh \delta_P}{\sinh \delta_A} \qquad \text{max. cy. amperes } \angle, \quad (35)$$

so that

$$I_{Pk} = I_{P\alpha} (1 - \epsilon^{-2k\delta_A}) = I_{P\alpha} \cdot 2\epsilon^{-k\delta_A} \sinh k\delta_A$$

$$= I_{P\alpha} w \qquad \text{max. cy. amperes } \angle. \quad (36)$$

This means that the growth coefficient w_k, after the passage of the kth reflection back from B, is the same for both the voltage and current at P. It also means that the impedance of the line PB and

TABLE V.

THE GROWTH FACTOR.

k	Growth Factor w. Numeric ∠	Receiving-end Voltage Max. cy. Volts ∠		Sending-end Current, Max. cy. Amps. ∠			
		Time M. Sec.	$E_{B,k}$	Time M. Sec.	Resultant of k Waves, $I_{A\alpha}$ w.	(k+1)th Reflected Wave, $I'_{A(k+1)}$	Total Vector Resultant, I_{Ak}
		t		t			
1	0.3012 ∠ 17° 3′32″	4.3	239.7 ∠ 93°32′28″	8.6	0.7079 ∠ 1°26′47″	0.2963 ∠ 2°40′26″	1.004 ∠ 0°13′52″
2	0.5164 ∠ 14° 6′11″	12.9	411.0 ∠ 96°29′49″	17.2	1.2135 ∠ 1°30′34″	0.2126 ∠ 9°44′53″	1.424 ∠ 2°43′54″
3	0.6692 ∠ 11°31′30″	21.5	532.5 ∠ 99° 4′30″	25.8	1.5726 ∠ 4° 5′15″	0.1525 ∠ 16°49′19″	1.722 ∠ 5°12′24″
4	0.7769 ∠ 9°18′20″	30.1	618.3 ∠ 101°17′40″	34.4	1.8256 ∠ 6°18′25″	0.1094 ∠ 23°53′46″	1.930 ∠ 7°17′19″
5	0.8521 ∠ 7°25′18″	38.7	678.1 ∠ 103°10′42″	43.0	2.0024 ∠ 8°11′27″	0.0785 ∠ 30°58′12″	2.078 ∠ 9°34′53″
6	0.9040 ∠ 5°50′43″	47.3	719.5 ∠ 104°45′17″	51.6	2.1245 ∠ 9°46′ 2″	0.0563 ∠ 38° 2′38″	2.174 ∠ 10°28′14″
7	0.9394 ∠ 4°32′48″	55.9	747.6 ∠ 106° 3′12″	60.2	2.2076 ∠ 11° 3′57″	0.0404 ∠ 45° 7′ 5″	2.241 ∠ 11°38′27″
8	0.9631 ∠ 3°29′23″	64.5	766.5 ∠ 107° 6′37″	68.8	2.2634 ∠ 12° 7′22″	0.0290 ∠ 52°11′31″	2.291 ∠ 13° 8′ 5″
9	0.9789 ∠ 2°38′42″	73.1	778.9 ∠ 107°57′18″	77.4	2.3000 ∠ 12°58′ 3″	0.0208 ∠ 64°15′58″	2.313 ∠ 13°22′12″
10	0.9887 ∠ 1°58′41″	81.7	786.8 ∠ 108°37′19″	86.0	2.3233 ∠ 13°38′ 4″	0.0149 ∠ 66°20′24″	2.333 ∠ 13°55′35″
11	0.9948 ∠ 1°27′36″	90.3	791.7 ∠ 109° 8′24″	94.6	2.3465 ∠ 14°32′57″	0.0077 ∠ 80°29′17″	2.350 ∠ 14°43′13″
12	0.9985 ∠ 1° 3′48″	98.9	794.5 ∠ 109°32′12″	103.2	2.3512 ∠ 14°49′54″	0.0055 ∠ 87°33′43″	2.352 ∠ 14°57′35″
13	1.0005 ∠ 0°46′51″	107.5	796.2 ∠ 109°49′ 9″				
∞	1.0000 ∠ 0° 0′ 0″	∞	795.8 ∠ 110°36′ 0″	∞	2.3500 ∠ 15°36′45″	0	2.350 ∠ 15°36′45″

the load σ, as developed at P, will be the same, after the passage of the kth reflected wave of voltage and current, as in the final steady state or

$$Z_{Pk} = \frac{E_{Pk}}{I_{Pk}} = z_0 \tanh \delta_P = Z_{P\infty} = \text{constant} \qquad \text{ohms} \angle. \quad (37)$$

It is here assumed that the kth reflection of voltage from B has passed P, and also the kth reflection of current, as the two are, in general, dephased by a definite amount.

It may be noted that when, as in Fig. 9, the current is observed at the A end of the line, the oscillogram includes, with the kth reflection from B, the $(k+1)$th outgoing wave from A. The point P of observation would have to be shifted to a suitable distance from A, in order to separate these two impulses. Consequently, when summing up the growth of current at A, the $(k+1)$th outgoing wave must be added to I_{P_k}. This increment is

$$I'_{Ak} = I_0(n-1)^k \epsilon^{-k\theta} = I_0 \epsilon^{-2k\delta A} \qquad \text{max. cy. amperes} \angle. \quad (38)$$

The accompanying Table V. shows the successive values of the growth coefficient w for the artificial line under test from $k = 1$ to $k = 13$ inclusive, both for voltage at B and current at A.

The vector diagram of Fig. 15, shows the planevector increase of voltage at B and current at A for the case represented by the oscillogram, Fig. 9. The voltage $Oa = 239.7 \angle 93°.33'$ and is the first wave at B, including immediate reflection there. The angle $XOa = 93°.33'$, or OX, represents the standard phase of impressed e.m.f. at A. If the line had been of exactly a quarter wave-length, this angle XOa would have been reduced to just one quadrant. This wave Oa commences to arrive at B, 4.3 milliseconds ($93°.55$ electrical degrees on a 60.6 $\sim$ circuit) after closing the switch at A. The second wave reflection at B will commence to develop after the outgoing wave has run three times over the line (AB, BA, AB), or a total lapse of 12.9 milliseconds after switch closing. Its vector value in the Table is $172.0 \angle 100°.37'$ and it is represented by ab in Fig. 15.

Relations between the transmission-reflection coefficients in **the** *transient state and the position angle at B in the subsequent steady state:* Referring to Fig. 3, and to the load of σ vector ohms at B connected to a uniform line of surge impedance z_0, we know that in the steady a.-c. state, the position angle δ_B at B is defined by

$$\tanh \delta_B = \frac{\sigma}{z_0} \qquad\qquad \text{numeric} \angle . \quad (39)$$

But

$$\tanh \delta_B = \frac{\epsilon^{\delta_B} - \epsilon^{-\delta_B}}{\epsilon^{\delta_B} + \epsilon^{-\delta_B}} = \frac{1 - \epsilon^{-2\delta_B}}{1 + \epsilon^{-2\delta_B}} \qquad\qquad \text{numeric} \angle . \quad (40)$$

Hence

$$1 - \epsilon^{-2\delta_B} = \frac{2\sigma}{z_0 + \sigma} = m = 2 - n = 1.9333 + j0.00496$$
$$= 1.9333 \angle 0° 8' 49'' \qquad \text{numeric} \angle , \quad (41)$$

$$- \epsilon^{-2\delta_B} = \frac{\sigma - z_0}{z_0 + \sigma} = m - 1 = 1 - n = 0.9333 + j0.00496$$
$$= 0.93331 \angle 0° 18' 16'' \qquad \text{numeric} \angle , \quad (42)$$

$$1 + \epsilon^{-2\delta_B} = \frac{2z_0}{z_0 + \sigma} = 2 - m = n = 0.0667 - j0.00496$$
$$= 0.06689 \diagdown 4° 15' 10'' \qquad \text{numeric} \angle , \quad (43)$$

$$\epsilon^{-2\delta_B} = \frac{z_0 - \sigma}{z_0 + \sigma} = 1 - m = n - 1 = - 0.9333 - j0.00496$$
$$= 0.93331 \diagdown 179° 41' 44'' \qquad \text{numeric} \angle , \quad (44)$$

$$\delta_B = \operatorname{logh} \sqrt{\frac{1}{1 - m}} = \operatorname{logh} \sqrt{\frac{1}{n - 1}} = 0.03451 + j1.56814$$
$$= 0.03451 + \underline{j0.9983} \qquad \text{numeric} \angle , \quad (45)$$

Here m is the voltage transmission
coefficient at junction BC
$-(1 - m) = m - 1$ is the voltage reflection
coefficient at junction BC
n is the current transmission
coefficient at junction BC
$-(1 - n) = n - 1$ is the current reflection
coefficient at junction BC

The Energy Content of an Outgoing Wave.—Fig. 18 presents a diagrammatic view of a single pair of outgoing waves from the generator A on to the uniform line AB, E being the voltage wave
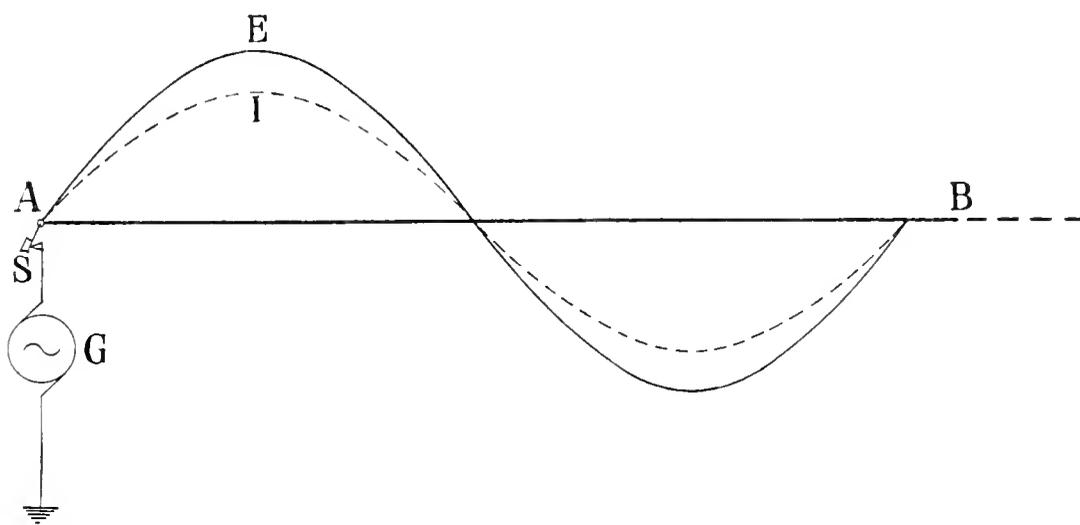
FIG. 18. Diagram of Single Wave Current and E.M.F., launched on a Uniform Distortionless Line.

and I the current wave. If the line is taken as distortionless, in the simplest case, the two waves will be emitted in cophase. The maximum cyclic value of the sinusoidal impressed e.m.f. being E_A volts, and the linear capacitance c farads per km., the electric energy given to the wave in an element of length dx km. will be $e^2(c/2)dx$ joules, where e is the instantaneous value of the e.m.f. The total electric energy in the wave will be $\dfrac{E_A^2}{2} \cdot \dfrac{c}{2} \cdot \lambda$ joules, where λ is the length of the wave in km.; because $E_A^2/2$ is the average square of e integrated over the wave-length. This electric energy is distributed in the dielectric in the form $w_e = B_e^2/8\pi\kappa$ ergs per c.c., where B_e is the electric flux density in "statgausses," and κ the inductivity of air. The frequency of the impressed e.m.f. being $f \sim$, the rate of delivering electric flux energy to the line is

$$P_e = \frac{E_A^2}{2} \cdot \frac{c}{2} \cdot f\lambda = \frac{E_A^2 \cdot c}{4} \cdot v \qquad\qquad \text{watts.} \quad (46)$$

The wave attenuates as it advances along the line, but the last equation expresses the initial power of supplying electric flux into

the dielectric at the end A of the line. The quantity v is the apparent velocity of transmission.

Similarly, if l is the linear inductance in henrys per km., the sinusoidal outgoing current at A has an instantaneous value i and a maximum cyclic value I_0 amperes, the magnetic energy in an element dx of the line is $i^2(l/2)dx$ joules. The total magnetic energy in a complete outgoing wave as it passes A is $(I_0^2/2) \cdot (l/2) \cdot \lambda$ joules. But

$$I_0 = \frac{E_A}{z_0} = \frac{E_A}{\sqrt{l/c}} = E_A \cdot \sqrt{\frac{c}{l}} \; ; \text{ so that } I_0^2 = E_A^2 \cdot \frac{c}{l},$$

or

$$\frac{I_0^2}{2} \cdot \frac{l}{2} = \frac{E_A^2}{2} \cdot \frac{c}{2} \qquad\qquad \text{joules.} \quad (47)$$

The magnetic energy in the wave is therefore $(E^2/2) \cdot (c/2) \cdot \lambda$ joules, which is the same amount as the electric energy. The magnetic energy is distributed in the dielectric as volume energy of magnetic flux of the type $w_m = B_m^2/(8\pi\mu)$ ergs per c.c., where B_m is the magnetic flux density in gausses, and μ the permeability of the air. $B_c = B_m$ numerically, and $w_c = w_m$ ergs/c.c. The energy of any initial outgoing wave is thus half electric flux energy, and half magnetic energy. The rate of delivering this magnetic energy at A is

$$P_m = \frac{E_A^2}{2} \cdot \frac{c}{2} \cdot f\lambda = \frac{E_A^2 \cdot c}{4} \cdot v \qquad\qquad \text{watts.} \quad (48)$$

Thus $P_m = P_c$. The total power

$$P = \frac{E_A^2 c}{2} \cdot v = \frac{I_0^2 l}{2} v \qquad\qquad \text{watts.} \quad (49)$$

The mechanism of electric power transmission, as contemplated in the initial transient state, is the energization of the dielectric with electric and magnetic fluxes, which at each point have equal numerical values and volume energies, and, in shipping off these slabs of flux at the transmission speed v. Continual reflections of these waves, from both ends of the line, subsequently build up a standing-

wave steady state, in which the volume energy of electric flux is different from, and ordinarily much greater than that of the magnetic flux, at any one point in the dielectric. The transmission process retains, however, the same general character, the effect being one of summation of travelling waves and wave energies.

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without pretensions as to completeness.

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List of Symbols Employed.

α	Linear hyperbolic angle or propagation constant of a uniform line	(hyps/wire km.).
$B = C\omega$	Total susceptance of a line	(mhos).
$b = c\omega$	Linear susceptance of a line.	(mhos/w.km.).
B_e	Electric flux density in a dielectric (statgausses, or $\kappa \times$ statvolts/cm.).	
B_m	Magnetic flux density in a dielectric (gausses, or μ gilberts/cm.).	
$\beta°$	Phase angle of lag	(circular degrees).
C	Total capacitance of a line	(farads).
c	Linear capacitance of a line	(farads/w. km.).
$\delta_A, \delta_B, \delta_P$	Position angles at sending end, receiving end, and intermediate point on a line, in the steady state	(hyps $\angle$).
dx	Small element of line length	(km.).
E_A, B_B, E_{Am}	Max. cyclic voltage at sending end and at receiving end of a line, in the steady state; also scalar max. value	(volts $\angle$).
$E_{Pk}, E_{P\infty}$	Transitory voltage at point P after the kth reflection from B and in the steady state	(volts).
e, e_r, e_s	Instantaneous voltage generally, at receiving end, at sending end	(volts).
$\epsilon = 2.718\ldots$	Napierian base	(numeric).
f	Impressed frequency	(cycles per sec.).
G	Total leakance of a line	(mhos).
g	Linear leakance of a line	(mhos/w. km.).
$\theta = \theta_1 + j\theta_2$	Hyperbolic angle of a line and its components	(hyps $\angle$).
$\theta' = \theta_1' + j\theta_2'$	Angular distance of a point on a line from A, the sending end	(hyps $\angle$).
$\theta'' = \theta_1'' + j\theta_2''$	Angular distance of a point on a line from B the receiving end	(hyps $\angle$).
I_A, I_s	Current at sending end of the line	(max. cy. amperes $\angle$).
I_B, I_r	Current at receiving end of the line	(max. cy. amperes $\angle$).
I_0	Initial outgoing current at A	(max. cy. amperes $\angle$).
$I_{Pk}, I_{P\infty}$	Transitory current at point P after the kth reflection from B, and in the steady state	(amperes $\angle$).
i, i_r, i_s	Instantaneous current generally, at receiving end, at sending end	(amperes $\angle$).
$j = \sqrt{-i}$		
k	Number of arrival wave, or of a B reflected wave, at a point P	(numeric).
κ	Electric inductivity of a dielectric	(statgausses/statsvolts-per-cm.).
$\mathcal{L}$	Total inductance of a line	(henrys).
L	Length of a line	(km.).
l	Linear inductance of a line	(henrys/w. km.).
λ	Wave length on a line	(km.).

m Vector voltage transmission coefficient at junction
(numeric $\angle$).

μ Magnetic permeability   (gausses/gilberts-per-cm.).

n Vector current transmission coefficient   (numeric $\angle$).
also the number of single wave passages over a line per
second   (numeric/sec.)

$P = P_e + P_m$ Total average power at sending end of a line in transient
state   (watts).

P_e, P_m Average power of transmitting electric flux and magnetic
flux along line, at A (watts).

$\pi = 3.1415 \ldots$ (numeric).

R Total resistance of a line   (ohms).

r Linear resistance of a line   (ohms/w. km.).

σ Impedance of load at B (ohms $\angle$).

T Time of transit of waves along line from A to B, or B to A
(seconds).

T_1 Time of transit of waves along line from A to P (seconds).

T_{P1}, T_{P2}, T_{Pk} Time of transit of first, of second and of kth wave reflec-
tion from B to P (seconds).

t Time elapsed from switchclosure at A (seconds).

v Velocity of propagation of waves along line   (km./sec.).

w, w_k Growth coefficient of waves at point P in transient state,
coefficient after kth reflection   (numeric $\angle$).

w_e, w_m Volume energy in dielectric of electric flux and of magnetic
flux   (ergs/c.c.).

$X = \mathcal{L}\omega$ Total reactance of line   (ohms).

x Linear reactance of line   (ohms/w. km.).

Y Total admittance of line   (mhos $\angle$).

Z Total impedance of line   (ohms $\angle$).

z_0 Surge impedance of line   (ohms $\angle$).

Z_{Pk}, Z_{Pa} Impedance at and beyond a point in a line after kth reflec-
tion from B, and in steady state   (ohms $\angle$).

ω Impressed angular velocity   (radians/sec.).

logh   Hyperbolic logarithm, or logarithm to Napierian base.

hyp   Hyperbolic radian.

w. km.   Wire kilometer.

r.m.s.   Root mean square.

$|E|$ Size of complex E.

U. S. NAVY MV TYPE OF HYDROPHONE AS AN AID AND SAFEGUARD TO NAVIGATION.

By H. C. HAYES, Ph.D.,

Physicist, Sound, U. S. Navy.

(*Read April 24, 1920.*)

SUMMARY.

The experimental work in connection with hydrophone development, which the United States Navy has carried out during the past year, has demonstrated that the MV type of hydrophone can effectively aid and safeguard navigation in the following ways:

1. By hearing and locating a moving propeller-driven vessel at ranges varying from 2 to 10 miles, depending upon the amount of noise which the vessel makes and providing the depth is within 100 fathoms.

2. By accurately determining the direction of submarine sound signals, located at fixed points along the coast and at harbor entrances, at various ranges up to 30 miles, depending upon the amount of local or water noises encountered.

3. By giving a continuous sounding record while underway at any speed for depths less than about three times the length of the vessel.

4. By hearing, locating, and giving the course of any vessel equipped with a suitable submarine sound signal at ranges up to 30 miles.

5. By affording a means of exchanging code messages between vessels equipped with the proper apparatus up to ranges of 20 miles in water of any depth, thus giving an auxiliary to the radio.

The results of the various tests that have thus far been carried out indicate that this type of hydrophone will prove capable of further aiding and safeguarding navigation in the following ways:

6. By giving a fairly accurate, intermittent sounding record while the vessel is under way in water of any depth, providing the vessel is equipped with a suitable submarine sound-signaling device.

7. By giving the distance of a submarine sound signal.

8. By locating icebergs, derelicts, or precipitous coasts at ranges sufficient for avoiding collisions.

HYDROPHONES DEVELOPED BY THE U. S. NAVY.[1]

The hydrophones developed by the United States Navy differ from all others in that they employ a multiplicity of non-resonant, underwater sound receivers, having sufficient time lag (compensation) introduced into the path of energy traverse between each receiver and the ear to bring the energy from all the receivers to the ears in phase.

The receivers are placed at equal intervals along a horizontal line. The dimensions of the group of receivers (length of line) is sufficiently great to cause an appreciable change in phase relations between the responses from the several receivers whenever the direction of the sound-source relative to the line of receivers is changed.

Navy hydrophones employing multiple receivers are of two classes, namely; those employing fixed compensation wherein the line of receivers can be rotated about a vertical axis, and those employing variable compensation wherein the receivers are fixed in position. The present paper deals with the latter class of hydrophones, the so-called " MV Types."

WHY THE NAVY TESTED THE ABILITY OF THE MV HYDROPHONE TO SAFEGUARD NAVIGATION.

At the time of the Armistice the MV type of hydrophone, although not completely developed, was proving to be superior to other types of on-board installations. Accordingly when the prob-

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[1] For a more complete description of various types of hydrophones, see paper " Detection of Submarines," by Dr. H. C. Hayes, PROCEEDINGS OF AMERICAN PHILOSOPHICAL SOCIETY, Vol. XIX., No. 1, 1920.

lem of transporting our troops back again arose it was suggested
that this device, if installed on transports, might prove to be of
value in safeguarding the lives of these men during fog or other
conditions of low visibility. This suggestion was strongly backed
by Rear Admiral B. C. Decker, U.S.N., then Senior Member of the
Special Board on Anti-Submarine Devices, and by Captain J. R.
Defrees, U.S.N., Secretary of the Board, and led to the equipping
of the U. S. S. *Von Steuben* with an electrical MV hydrophone for
the purpose of ascertaining whether or not such a device could effec-
tively serve as an aid and safeguard to navigation.

Experimental Results Obtained on the U. S. S. Von Steuben.

The writer was fortunate in having charge of the hydrophone
installation on the *Von Steuben* during the first trip from Hoboken
to Brest and return, a trip which in his opinion will come to be re-
garded as epoch-making in the annals of navigation.

The *Von Steuben* proceeded at one third speed while leaving New
York harbor. During this period neighboring tugboats and ferries
were readily located by determining the direction of their propeller
sounds. Arrangements had been made to have the lightships along
the approach to New York harbor sound their submarine bells and
the signals from all these lightships (Ambrose, Fire Island, Cardinal,
and Finch) were picked up in turn by the hydrophone and the ves-
sels located before they could be seen. Several times signals from
two or three of the lightships could be heard and located at the same
time and the position of the *Von Steuben* determined by cross-
bearings.

It was not expected that the bell signals from the Nantucket
lightship could be heard as the course of the *Von Steuben* lay well
to the southward of this vessel and the listeners turned in for the
night. The writer's assistant, Ensign D. W. McElroy, U.S.N.R.F.,
having awakened at about 1 A.M., decided to listen on the hydro-
phone and heard the bell signals from this vessel coming in clearly
and distinctly. The *Von Steuben* at this time was steaming at full
speed. The bell was followed for two hours, during which time the
light on the Nantucket lightship was not sighted. The range and

position of this vessel relative to the *Von Steuben* were determined later by triangulation, using the distance covered during the two hours as a base-line. These results checked closely with determinations made by dead reckoning and showed that the lightship was never approached closer than 32 nautical miles and that the greatest range at which the bell signals were heard was about 40 miles.

Thus within a few hours after leaving Hoboken, it was apparently demonstrated that navigation could be effectively safeguarded by the MV hydrophone, since by its aid the direction of submarine bell signals was accurately determined at ranges varying from 15 to 40 miles and the propeller sounds of near-by vessels heard and the vessels located thereby at ranges sufficient for avoiding collisions. With such information at his disposal, the navigator should be able to take his vessel into or out of port during fog or other conditions of low visibility.

The next day it was a matter of disappointment to find that the propeller sounds of the *Von Steuben* could not be heard in depths much greater than 500 fathoms. This result led to the important discovery that the MV hydrophone is able to give a reliable and continuous record of the depth of water beneath a vessel, steaming at any speed, up to depths of approximately three times the length of the vessel and that this record becomes more and more accurate as the depth of water becomes less.

Only Sound Reflected from the Sea-Bottom is Heard on Hydrophones Located Near the Surface.

The fact that propeller sounds of the *Von Steuben* could not be heard in deep water led at once to the conclusion that the hydrophone is affected only by sound that has been reflected from the sea-bottom. Two explanations of this fact are offered.

Referring to Fig. 1, sound from a source such as a propeller (S) reaches the hydrophone receiver (H) by three different paths, namely: S—P—H, S—R—H, and S—O—H respectively. If the distance S—H is great with respect to the distance P—R, that is, if the separation of source and receiver is great compared to their submersion below the surface, then the two paths S—P—H and

S—R—H are nearly equal. The reflection at (P), being from a rare to a dense medium, introduces a change of phase of one half the wave-length and as a result the sound which travels directly

MUTUAL CANCELLATION OF DIRECT AND SURFACE-REFLECTED RAYS
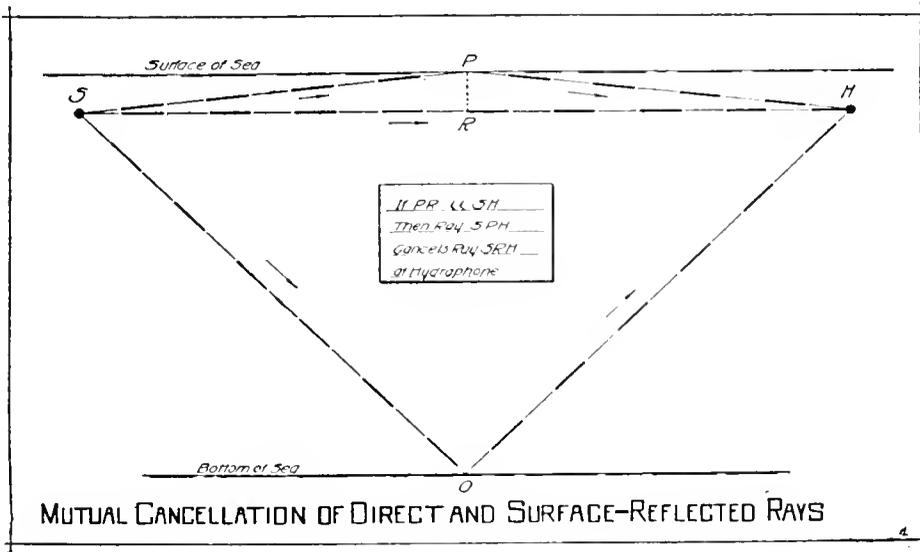
FIG. 1.

from (S) to (H) and that which is reflected from the surface will give almost complete interference at the receiver (H) and only the sound reflected from the bottom (O) will be heard.

WAVE DISTORTION DUE TO PRESSURE RELEASE AT SURFACE
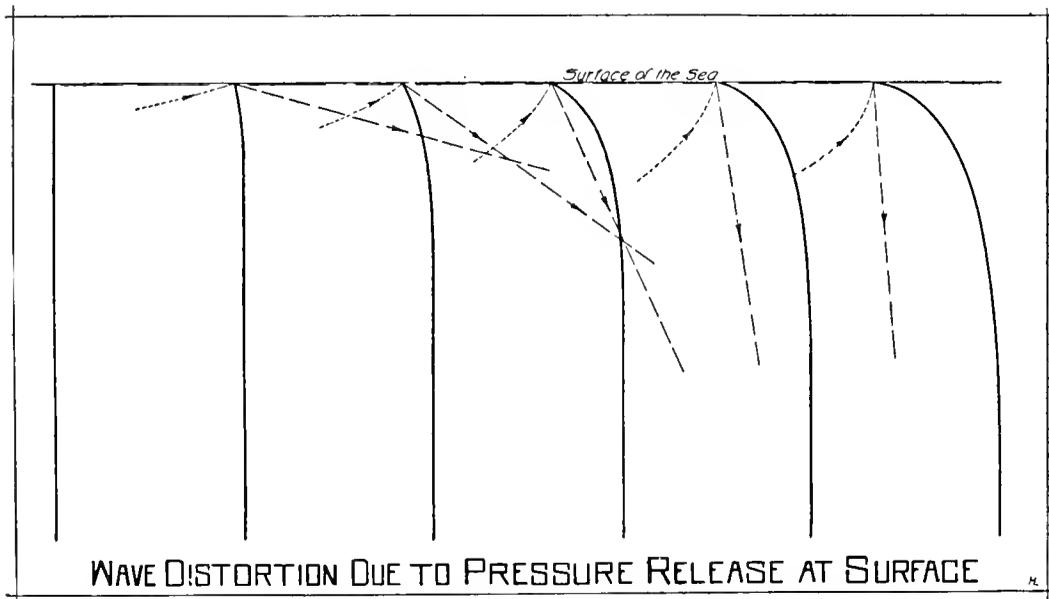
FIG. 2.

Referring to Fig. 2, the surface of the water represented by the horizontal line is a region of pressure release and as a result the rare

and dense portions of the sound waves will not remain perpendicular to this surface. If the sound travels from left to right the wave front will be distorted to the left as shown by the full curved lines. This distortion becomes greater as the sound travels farther from the source, and at considerable distance it is conceivable that all sound reaching the surface is travelling in a direction nearly perpendicular to it and thus will be reflected nearly vertically downward. If this distortion extends to a sufficient depth, neither the direct nor the surface-reflected sound ray will reach the distant receiver placed near the surface. Under such conditions only sound reflected from the sea-bottom will be heard.

Experiments for determining which of the above explanations is valid have not been undertaken to date. However, when listening to bell and oscillator signals, it has been noticed that the harmonics are more prominent relative to the fundamental at the first instant of response than during the rest of the signal. This fact tends to substantiate the first explanation. The slight difference in path length between the direct and surface-reflected sound introduces more phase difference between the high-pitched components of the sound than in the case of the fundamental and therefore the harmonics are less perfectly neutralized by interference at the receiver than is the fundamental. The sound at the receiver resulting from these two paths consists largely of harmonics and this is heard an instant before the sound which is reflected from the sea-bottom as the latter has travelled a somewhat longer path.

A New Method of Sounding.

Since the only propeller sound heard by a hydrophone located at a distance and near the surface is the component reflected from the sea-bottom, it follows that the depth of water can be determined from the angle which the reflected sound makes with a fixed line in a plane determined by the sound source and the reflected ray—provided the distance between the hydrophone and sound-source is known. Conversely, the distance between the hydrophone and the sound-source can be determined if the depth of water is known.

Referring to Fig. 3, let (H) represent the position of the MV hydrophone and (P) the ship's propeller. The sound heard by (H) has traversed the path P—B—H, making an angle ϕ with the surface. If ($2L$) is the distance between the propeller and the hydro-

For deeper water $D = C + H = C + L \tan \phi$
For shallower water $D = C + H = C + L' \tan \phi'$

SOUNDING BY ANGLE OF REFLECTION METHOD
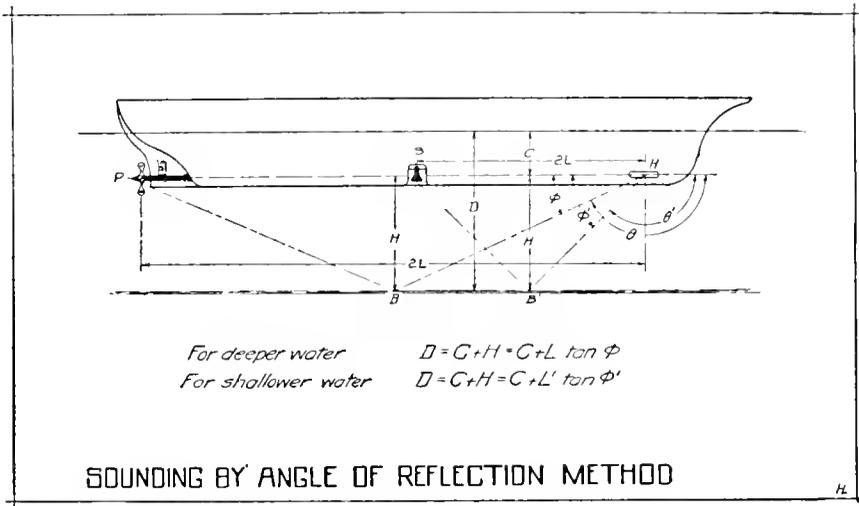
FIG. 3.

phone, both located a distance (C) below the surface, and if the sea-bottom is a horizontal plane, then the depth (D) is given by the equation

$$D = C - L \tan \theta,$$
$$= C + L \tan (\pi - \theta),$$

or

$$D = C + L \tan \phi.$$

This equation will be referred to as the " sounding equation " and the angle ϕ will be referred to as the " sounding angle." It is to be noticed that the compensator scale is designed to feature θ, the angle the sound makes with the ship's keel extended forward, in order to give directly the relative bearing of surface vessels. The sounding angle ϕ is the supplement of this angle.

The range of a vessel ahead or astern can be determined roughly if the depth of water is known, since the hydrophone determines the angle which its reflected sound signals make with the surface.

Referring to Fig. 4, where S_1 or S_2 represents an artificial sound-source upon a vessel ahead or astern of the vessel equipped with the hydrophone (H), we have

$$R_1 = 2D \cot \theta_1,$$
$$R_2 = 2D \cot \phi_2,$$

the depth (D) being taken from the chart. It is to be noticed that for ranges ahead the compensator reading, θ, occurs in the equation while for ranges astern the "sounding angle," ϕ, is used.

METHOD OF SOUNDING AND RANGE FINDING BY M-V HYDROPHONE
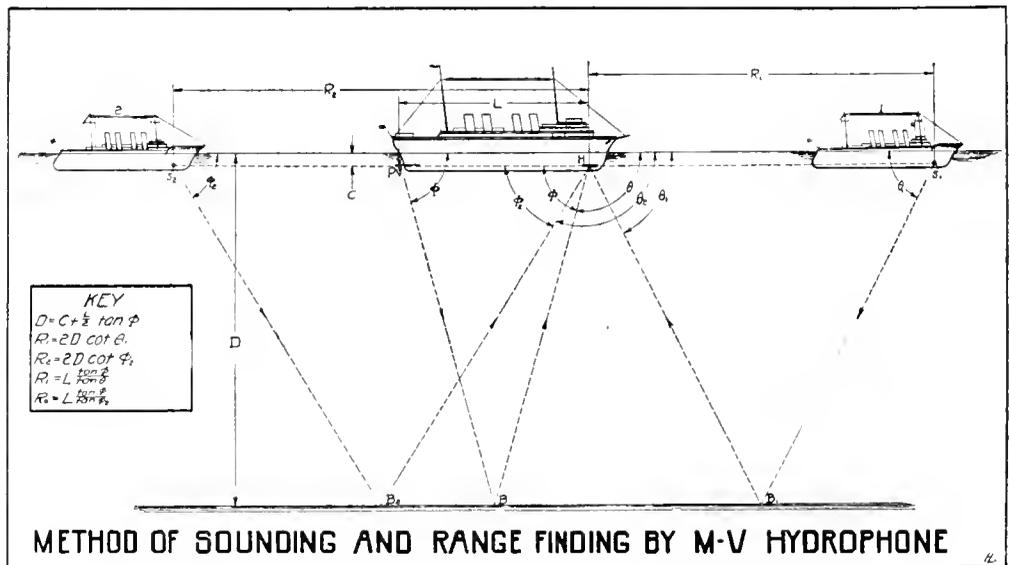
FIG. 4.

If the depth is not too great, (D) can be determined by the hydrophone as outlined above and the range formulæ become

$$R_1 = L \frac{\mathrm{Tan}\,\Phi}{\mathrm{Tan}\,\theta_1},$$

$$R_2 = L \frac{\mathrm{Tan}\,\Phi}{\mathrm{Tan}\,\Phi_2},$$

where (R) is the range to be determined, (L) the distance between the sound-source and hydrophone on the listening vessel, and θ_1, θ_2, and Φ are the angles which the reflected sound from the three vessels make with the surface as shown.

It is evident that the range to which these formulæ will give reasonably accurate determinations is proportional to the depth of water in which the vessels are operating.

The equation connecting (D), the depth, and Φ, the angle which the reflected sound makes with the surface, becomes somewhat com-

plicated if the line of hydrophone receivers is not parallel with the surface and with the center-line of the vessel, or if the sea-bottom is not horizontal. This complication, however, consists largely in the addition of constant terms. Pitching of the vessel or variation of the sea-bottom from a horizontal plane causes the angle Φ to vary somewhat from the ideal conditions cited but, as will be shown later, such variations do not seriously interfere with the determination of depth.

Both Vertical and Horizontal Angles Determined by MV Hydrophone.

The MV hydrophone measures the angle included between a line passing through the receivers and an intersecting line defining the direction of the approaching sound. From conditions of symmetry the latter line can be rotated around the former without changing the required compensation. Otherwise stated, the same compensator setting will serve for sound traversing any element of the conical surface so generated. The angle of the cone is determined always by the compensator setting and if the line of receivers is parallel to the ship's keel in a vertical plane and to the water surface in a horizontal plane, the same compensator scale will serve for determining the direction with respect to the ships keel of sounds traversing either of these planes.

Errors Introduced by Pitch and Roll Readily Eliminated.

In general the hydrophone receivers are located along a line parallel with the ship's keel and at the same depth as the propellers. Under such conditions the compensator measures directly θ, the supplement of the sounding angle Φ—provided the vessel " rides on an even keel." Rolling of the vessel will not affect the determination of this angle but pitching will.

The angle of pitch for large vessels is very small except during unusually rough surface conditions and, except at such times, the error introduced by pitching of the vessel need not be considered. It has been found in practice that for large vessels the pitching motion is sufficiently slow to allow the operator to measure the sounding

angle while the vessel is in a horizontal position or to measure the angle at each end of the pitching motion. If the latter plan is pursued the average of the two angles gives the correct value.

Errors Introduced by Shelving Bottom Can be Eliminated.

A consideration of Fig. 5 shows that the errors introduced by shelving of the sea-bottom can be eliminated if a hydrophone and a sound-source are placed in both the bow and the stern of a vessel

METHOD FOR ELIMINATING ERROR DUE TO SHELVING BOTTOM
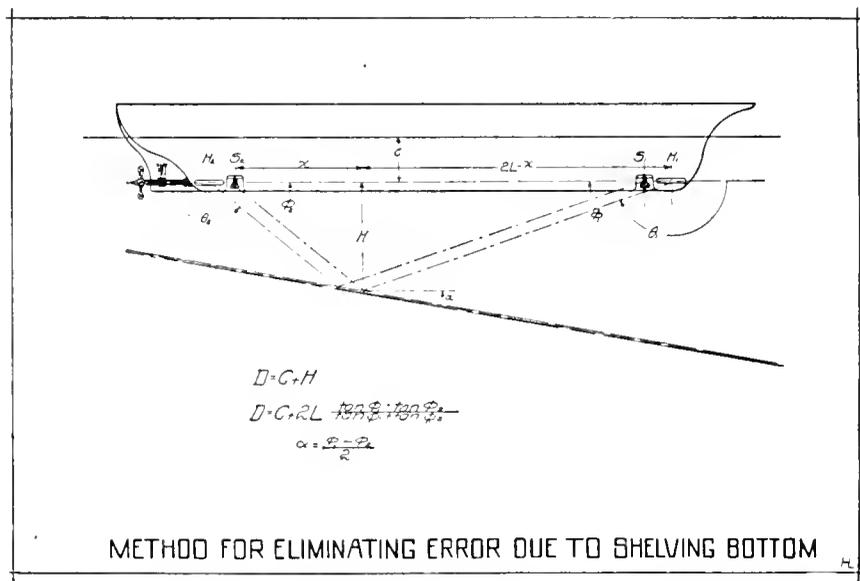
Fig. 5.

Let (S_1) and (H_1) represent a sound-source and hydrophone respectively, located near the bow of the vessel and (S_2) and (H_2) another sound-source and hydrophone located near the vessel's stern. Sound from (S_1) and (S_2) reflects from the same portion of the sea-bottom, making angles with the horizontal at (H_2) and (H_1) of Φ_2 and Φ_1 respectively.

If $(2L)$ is the horizontal distance between (S_1) and (H_2) and between (S_2) and (H_1), then

$$D = C + (2L - X) \tan \Phi_1,$$

and

$$D = C + X \tan \Phi_2.$$

Thence

$$D = C + 2L \frac{\tan \Phi_1 \cdot \tan \Phi_2}{\tan \Phi_1 + \tan \Phi_2}.$$

Moreover, the angle α which the sea-bottom makes with the keel of the vessel, assumed to be horizontal, is given by the relation

$$2\alpha = \Phi_2 - \Phi_1.$$

If $\Phi_1 = \Phi_2$, the formula reduces to the sounding equation, viz.:

$$D = C + L \tan \Phi.$$

In practice it has been found that shelving of the sea-bottom is seldom rapid enough to cause any great error in the determination of depth, especially for depths within 15 or 20 fathoms, and for purposes of navigation a single hydrophone located in the bow of the vessel and a sound-source located near the stern have been considered sufficient. Such an installation tends to err by giving too great depths when approaching shallow water and too small when approaching deep water. This error has been checked by taking soundings out and in on same course and found to be negligible in the most cases.

Soundings taken on a shelving bottom with any of the various types of sounding machines err in the some direction as do soundings given by the simple hydrophone installation described, if the sounding weight is launched from the stern of the vessel. Since the lead reaches bottom some distance behind the vessel, it will register too great depths when approaching shoal water and too small depths when entering deeper water. The hydrophone method has the advantage that the error is independent of the speed of the vessel while in case of the sounding machine the error increases with the speed.

Errors Introduced by Incorrect Determination of Sounding Angle.

The MV hydrophone determines direction by measuring the difference in time between reception of the sound by the two groups of receivers which connect with the two ears respectively; or, what amounts to the same thing, by determining the path difference between the sound-source and the two groups of receivers. This time difference or path difference is measured by introducing sufficient compensation into the paths connecting the receivers to the ears to

make the sound appear centered in the listener's head. It has been found in practice that the average listener can determine the path difference in water to within about one half inch.

Binaural Arm $\overline{AB} = C$
Compensation $d = C \cos \theta$
Error in Compensation $\pm \delta$
Error in Angle $\Delta \theta = \theta \cos^{-1} \frac{d \pm \delta}{C}$

ERROR IN ANGLE "θ" DUE TO ERROR IN COMPENSATOR SETTING
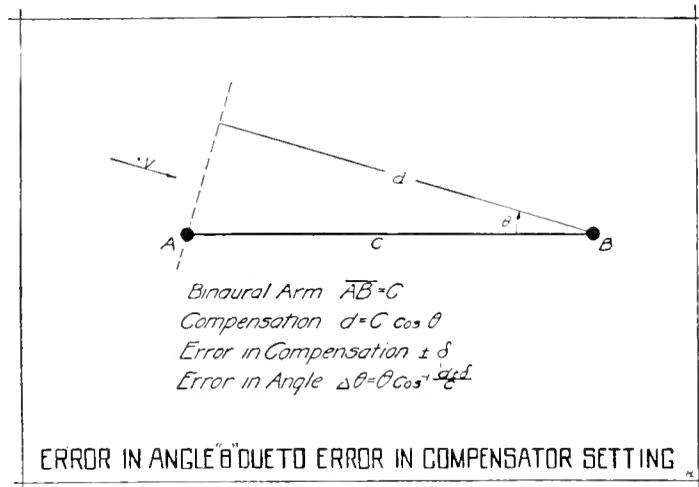
Fig. 6.

Referring to Fig. 6, it will be seen that this error due to the personal element may introduce a relatively large error in the determination of θ and hence the same error in the sounding angle Φ which is the supplement of θ.

For simplicity assume the hydrophone to consist of two single receivers (A) and (B), Fig. 6, one connecting with each ear and separated a fixed distance (C). Sound approaching from the direction represented by vector (V) makes an angle θ with the line joining the two receivers. The operator determines this angle by measuring the distance (d) to within one half inch. Calling this error δ we have the following relation

$$\theta = \cos^{-1} \frac{d - \delta}{C}.$$

The accuracy with which this equation determines θ is proportional to (C), the distance between the two receivers, and varies with the value of (d). Since the value of the cosine changes slowly with change of angle as the value of the angle approaches zero, it is evident that the value of δ will produce an abnormally large error in the determination of θ when the direction of the sound approaches parallelism with the line connecting the receivers. It is to be noticed that in determining the sounding angle Φ this condition is approached when the vessel enters shallow water.

The sounding equation, $D = C + L \tan \Phi$, on the other hand, would seem to predict that the depth of water (D) is determined with greater accuracy as the water becomes more shallow, since the value of the tangent varies less rapidly with variation of the angle as the angle approaches zero. This does not hold true, however, for the reason that the error in the determination of Φ becomes abnormally large as the value of this angle approaches zero and it results from these considerations that depths of from 2 to 5 fathoms are not determined with as great accuracy as depths from 10 to 20 fathoms if hydrophones of the type described are used. This type is shown in the left-hand diagram of Fig. 7, where the line of the receivers is horizontal and parallel with the ship's keel.

For small values of φ (Shallow water) 180°)θ)θ')90° so that θ' may be measured with less error than θ

ADVANTAGE OF INCLINED HYDROPHONE LINE FOR SOUNDING
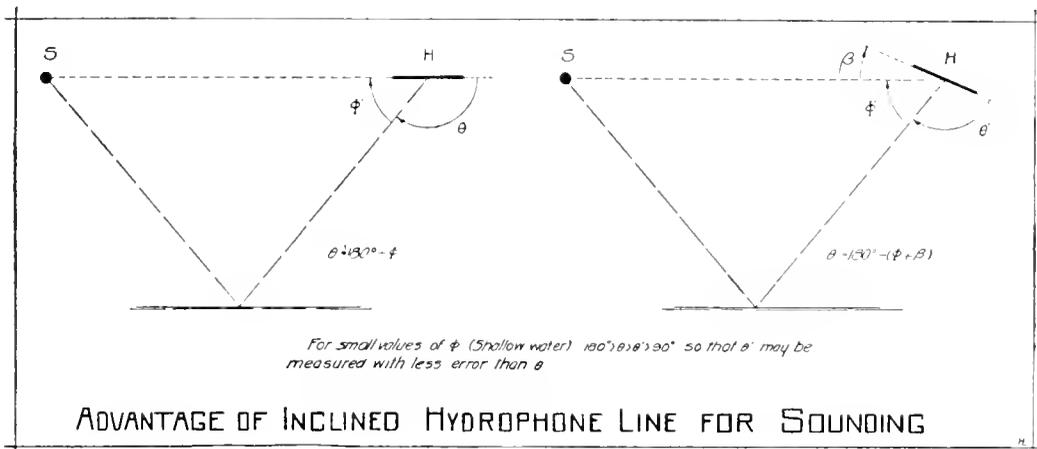
FIG. 7.

This weakness arises whenever the same hydrophone receivers are used for determining both the bearing of vessels or shore signals and also for taking soundings. It is readily removed if a separate set of receivers is installed for *sounding purposes only*. These receivers are mounted in a vertical plane parallel to the keel and along a line making an angle of about 30° with the surface, the forward end of the line of the receivers being lower as is shown in the right-hand diagram of Fig. 7. With such an arrangement of receivers the sounding angle Φ will be given by subtracting 30° plus the angle given by the compensator from 180°, and the compensator will only be required to determine angles between 60° and 150°. In this way the most accurate part of the compensator scale is utilized for deter-

mining depths and the determination then becomes progressively more accurate as the water becomes shallower.

The addition of a separate line of receivers does not complicate or materially increase the cost of the installation, since by means of a multiple-pole switch the same compensator can be used on all the receiver lines. The electrical compensator is provided with such a switch.

Another method of reducing the sounding error in shoal water, which is applicable to larger vessels, is as follows: If an artificial sound-source is placed near the center of the vessel, as shown at (S) in Fig. 3, it is evident that accurate shoal soundings can be taken without the addition of a line of receivers inclined to the horizontal. The reflected sound from this source does not approach parallelism with the line of receivers except for extremely shallow water. With such an arrangement an operator in taking deep soundings will make use of the stern sound-source (the propeller), while for soundings in shallow water he will utilize the centrally located sound-source.

It is evident, from a consideration of the sounding equation, that the error in the determination of the depth (D) resulting from the error in the determination of the sounding angle Φ will become abnormal when the depth is sufficiently great to cause this angle to approach 90°, since the value of the tangent then varies rapidly with change of angle. This weakness can be partially overcome by separating the sound-source and the hydrophone as far as possible. When the hydrophone and the sound-source are placed in opposite ends of the vessel, reliable soundings are given for depths as great as three times the length of the vessel.

GRAPHICAL REPRESENTATION OF ERRORS INTRODUCED BY INCORRECT DETERMINATION OF SOUNDING ANGLE.

In order that the nature and magnitude of the errors in sounding, due to incorrect determination of the sounding angle Φ, may be more clearly understood, these determining factors will be illustrated graphically.

In Fig. 8, the full line in the center of the shaded area gives the relation between depth and sounding angle Φ when the sounding equation

$$D \text{ (fathoms)} = 1 + 22.6 \tan \Phi$$

is plotted.   The constants (C) and (L) are given in fathoms and refer to the MV hydrophone installation on the U. S. S. *Bernadou*. The curve assumes that Φ is accurately determined.

DEPTH CALIBRATION
& LIMITS OF ERROR
FOR MV-16 HYDROPHONE
INSTALLED ON U.S. DESTROYER
ASSUMED PRECISION ± 0.2 AIR INCHES

COMPUTATION
COMPENSATOR READING - Θ
BASE LINE 2L-45.2 FATHOMS
SUBMERSION - 1 FATHOM
DEPTH D = 1+L TAN Φ FATHOMS
WHERE :   Φ = 180° - Θ
BINAURAL ARM C-28.98 AIR INCHES
NET COMPENSATION FOR ANGLE Φ:
d = C cos Φ   AIR INCHES
NET COMPENSATION FOR ANGLE Φ+Δ Φ
d+Δd = C cos (Φ+Δ Φ)
COMPENSATION ERROR Δd-0.2 AIR INCHES
ANGULAR ERROR Δφ = cos⁻¹ d+Δd - Φ
ERROR IN DEPTH AT ANGLE Φ
ΔD = L [TAN (Φ+Δφ) - TAN Φ]

Fig. 8.

It has been shown, however, that $\Phi = (\pi - \theta)$ where

$$\theta = \cos^{-1} \frac{d \pm \delta}{C}.$$

If now we take for δ the value $\pm$ o.2 inches of air path (which is equivalent to $\pm$ 0.87 inches of water path), this value being a conservative estimate of the precision of compensator setting, we may

ascertain the corresponding limits of error as a function of the depth by plotting the curves represented by the equation:

$$D \text{ (fathoms)} = 1 + 22.6 \tan \cos^{-1} \frac{d \pm 0.2}{28.98},$$

taking for the binaural arm (C) its value 28.98 inches in air (the water path is 126 inches) and for the variable (d) the net compensation of the line corresponding to various values of the sounding angle Φ.

These curves have been drawn, one on either side of the true sounding curve. Due to this personal error in determining Φ, the maximum limits of which are set as ± 0.2 air inches, it is evident that a given sounding is liable to fall anywhere within the shaded area bounded by these two curves. It is to be noticed that this area widens in a vertical direction at both ends of the curve, i.e., the error for very shallow and for great depths is greater than for intermediate depths. The hydrophone installation in question has the receivers installed along a horizontal line parallel to the ship's keel, as shown in the left-hand diagram of Fig. 7.

In Fig. 9 the maximum error is plotted against depth as abscissæ and shows how the error is reduced for small depths when the line of receivers is inclined to the ship's keel. The full line curve shows the maximum error for various depths when the line of receivers is parallel to the center line of the ship. The error increases rapidly for depths below 10 fathoms. The broken line curve made of long dashes gives the maximum error when the line of receivers is inclined 30° to the horizontal in the manner shown in the right-hand diagram of Fig. 7. Here the error at great depths is not materially increased. The third curve gives the error when the line of receivers is inclined 60°. This arrangement further reduces the errors slightly in shallow depths but clearly at the expense of increasing it considerably at greater depths.

It has been found that best results are given when the line of receivers is inclined about 30° to the keel. Such an arrangement reduces the error in shallow water sufficiently for all practical purposes and at the same time does not materially increase the error for greater depths.

In practice the compensator is provided with a separate scale which is calibrated to give soundings in fathoms. To determine the depth of water the listener adjusts the compensator until the propeller sounds or submarine signal sounds off his own vessel are binaurally centered and then reads off the value directly from the

CURVES OF MEAN ERROR
FOR HORIZONTAL & INCLINED
MV-16 HYDROPHONE

BASE LINE   45.2 FATHOMS
BINAURAL ARM   28.98 AIR INCHES
ASSUMED PRECISION   0.2 AIR INCHES

ERROR IN FATHOMS

DEPTH IN FATHOMS

LEGEND
——— HORIZONTAL
— — INCLINED 30°
----- INCLINED 60°
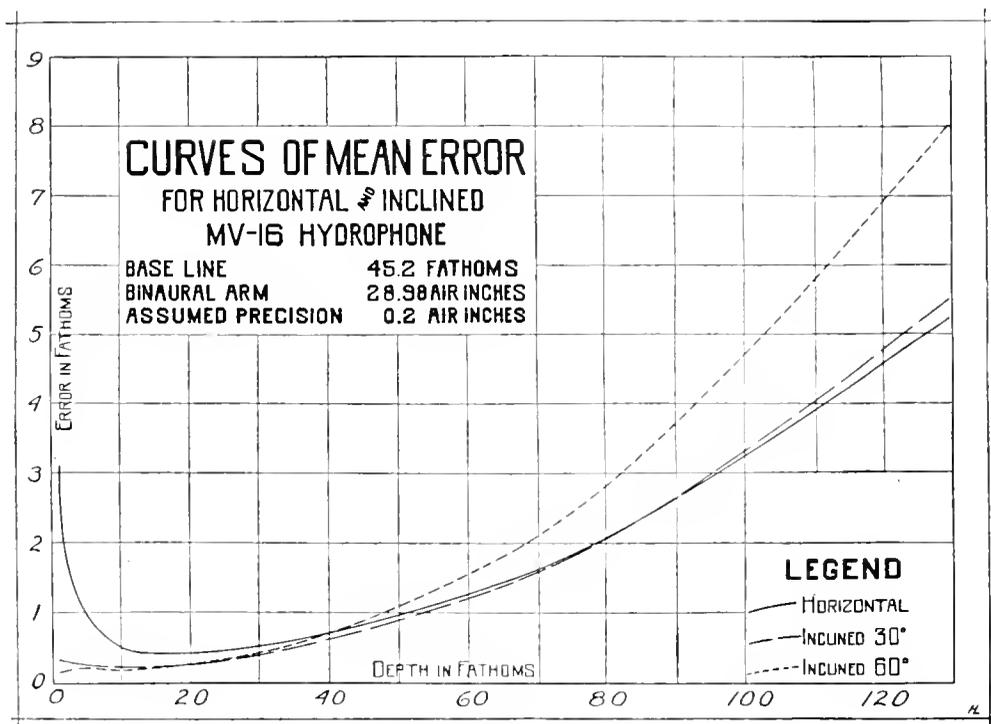
FIG. 9.

sounding scale. This operation takes but a few seconds, so that a continuous sounding record can be taken when desired and, as is shown, the record becomes more accurate as the water becomes shallower.

SOUNDING IN DEEP WATER.

The angle of reflection method only gives reliable soundings for depths less than three times the length of the vessel, but if the vessel is equipped with both an MV hydrophone and a proper submarine signal, an intermittent sounding record can be taken in water of any depth. Such soundings are determined by measuring the time required for a sound signal to travel to the bottom and reflect back again to the surface or, in other words, by measuring the time which elapses between the sounding of a signal and the response of its echo on the hydrophone.

This method of sounding, which is very simple in principle, is not new. It differs from the first method described in that it depends *upon the accurate measurement of a time interval* (a difficult operation in practice), whereas the new method depends *upon the measurement of an angle* (a comparatively easy operation). Moreover, the error in soundings due to incorrect determination of the time interval is as great for shallow as for deep water, whereas the error due to incorrect determination of the sounding angle becomes very small for shallow water.

The velocity of sound in sea water at the ordinary temperatures met in practice is roughly 4,400 feet per second. This velocity is so great that stop-watch methods are not sufficiently accurate for measuring the time intervals, since an error of one fifth second results in a discrepancy of over 70 fathoms in the determining of depth. The various laboratory methods of measuring time intervals with a high degree of accuracy require a skilled operator and in general can not be employed on board ships. Several devices designed for marine use in connection with this problem have been perfected but have all proven to be too complicated to be successfully operated by a ship's personnel.

The writer is at present developing a new method which looks very promising and by which the time interval between two signals can be determined with a high degree of accuracy on shipboard. The perfection of such a device will make possible the taking of soundings with a fair degree of accuracy in water of any depth while the vessel is steaming at full speed.

DETERMINATION OF THE RANGE OF A SOUND-SOURCE.

If both a radio and an underwater sound signal are sent simultaneously from one point, the distance to the same can be determined by measuring the time interval which elapses between reception of the two signals at a distant point. In this way lightships or other points provided with underwater navigation signals can be accurately located. This procedure has been tried by stop-watch methods with mediocre success, but it is believed that the device mentioned above will make it possible to determine the range of a sound-source with

the same high degree of accuracy. This apparatus, which can not be described at this time, makes use of the MV hydrophone.

Locating Vessels in Deep Water.

The experimental results, obtained on the *Von Steuben*, led to a belief that MV hydrophones could not safeguard navigation in deep water by locating propeller sounds of other vessels. Believing that this weakness could be removed if ships were equipped with a proper type of submarine sound signalling device, a series of experiments were carried out in mid-ocean between the U. S. S. *Von Steuben* and the U. S. S. *Wilkes* the latter vessel, a destroyer, being equipped with a submarine oscillator. The tests were conducted in depths varying from 1,000 to 2,500 fathoms.

The oscillator signals were heard clearly to a range of 35 miles when the *Wilkes* was abeam and from 10 to 20 miles when ahead or astern of the *Von Steuben*.

The range (R) of the *Wilkes* (see Fig. 4) was determined several times while she was running ahead of the *Von Steuben* by measuring the angle θ_1 which her oscillator signals, reflected from the sea-bottom, made with the horizontal and using for (D) the charted depth which was rather indefinite through the region wherein the experiments were conducted. Nevertheless, these ranges agreed fairly well with values computed from time and speed data or with optical measurements.

Both theory and subsequent researches indicate that the oscillator on the *Wilkes* was not best suited for these experiments, but the tests demonstrated beyond a doubt that the hydrophone can safeguard navigation in any depth of water if all vessels are provided with an MV hydrophone and a submarine oscillator. Such an equipment will then give the bearing and course of every vessel within a radius of from 15 to 40 miles. Furthermore, the range of vessels approximately ahead or astern can be roughly determined if the depth of water is known.

It is quite probable that in the future all sea-going vessels will be equipped with hydrophone apparatus of the MV or other approved type, together with a suitable sound-source. Then maritime law will

doubtless require submarine code signals to be sent out at frequent intervals during conditions of low visibility. These signals will designate the code number or " call " of the ship, its compass course and possibly the speed which it is making. Other vessels in the vicinity on receiving these signals and on obtaining a hydrophone bearing upon them will have at their disposal much valuable information which will aid them in steering a clear course and avoiding disastrous collisions.

Such bearings will be far more trustworthy than those afforded by fog whistles now universally used, not only because of the greater ranges at which they may be obtained but also due to the fact that the sea is a relatively homogeneous and stationary medium which permits the definite linear propagation of sound. Every navigator knows the unreliable nature of fog whistles which are not only deadened by a counter wind, thus giving an erroneous idea of range, but which frequently suffer erratic and wholly indeterminate refractions and reflections as they encounter fog banks and cross-currents of air. As a result their propagation is far from linear so that false bearings of their source are obtained from which dangerous emergencies sometimes arise.

Locating Icebergs, Derelicts, etc.

Because of its focusing ability, the MV hydrophone can determine the direction of comparatively faint sounds while the vessel, upon which it is installed, is underway. If the sounds come directly from the source, it gives the bearing of the source; but if the sound has been reflected, it gives the bearing of the reflecting surface.

Direct tests for locating icebergs and derelicts by hydrophone have not been undertaken to date but indirect evidence obtained while conducting tests at New London, Connecticut, leads strongly to the belief that such obstructions can be located by hearing and determining the direction of submarine sounds reflected from their surface. The writer has often located the piers of the railroad bridge at New London, Connecticut, by the reflected propeller sounds of the listening vessel and has also been able to locate Valiant Rock, which lies in the passage between Fishers and Little Gull Islands, and in a like

manner the South-West Ledge at the entrance of New London harbor.

Since ice forms an excellent reflecting medium for submarine sounds, as does also the hollow hull of a vessel, it seems certain that high-pitched oscillator signals should reflect from such surfaces with sufficient intensity to be heard on the hydrophone. In practice the listener would focus the hydrophone dead ahead and send intermittent sound signals with the oscillator. If at any time the signal appears binaurally centered, the sound is then being reflected from a surface dead ahead and collision with the same may readily be avoided.

Several years ago attempts were made to locate icebergs by the echo method but failed for want of a device that could give the direction of the reflected sounds. The MV hydrophone supplies this want and with its aid it is believed that the experiments when repeated will prove successful and introduce a means of preventing such appalling disasters as befell the ill-fated *Titanic*.

Character of the Sea-Bottom—Hydrographic Surveys.

The hand lead and the sounding machine not only give the depth of water but also the character of the sea-bottom. The latter information oftentimes is as valuable as the former in locating the position of a vessel. The question, therefore, naturally arises, " Can the hydrophone give any information concerning the character of the sea-bottom?"

The answer to this question is " Yes." The character of the reflected propeller sounds varies with change in the character of the sea-bottom both as to intensity and to quality. These variations are so marked that a trained listener needs only to travel back and forth over the same course but a few times before he is able to recognize various regions en route by the character of the propeller sounds.

While experimenting in Long Island Sound the writer has often noticed a decided change in the intensity of the propeller sounds when the listening vessel was off Saybrook. This change is doubtless due to the fact that the sea-bottom in this region is covered

with sediment brought down by the Connecticut River. Other regions in the Sound were also easily recognized but thus far no attempts have been made to identify any particular sound characteristic with a particular kind of sea-bottom. Doubtless experiments along this line will prove interesting and valuable.

The hydrophone is destined to be of great aid in accurate, rapid, and detailed hydrographic surveys, affording as it does a continuous sounding curve over any desired course, at the same time giving an indication of the character of the bottom. For such researches a special design of hydrophone having an extended and variable baseline would probably be used. Thanks to the extensive labors of the hydrographic bureaus the coastal waters of this and several other nations are well surveyed, but the advent of the hydrophone into this field will facilitate the checking and extension of this information so vital to navigation.

The Hydrophone as an Auxiliary to the Radio.

Another field in which the hydrophone will doubtless serve as an aid to navigation is that of auxiliary to the radio. It has been clearly demonstrated that by the use of a proper sound-source and hydrophone, code messages may be exchanged up to ranges of from 15 to 20 miles by vessels under way, so that this equipment may be advantageously used for handling the " short traffic " communications between adjacent vessels or from vessel to shore. With the rapid growth and expansion of radio science the problem of interference becomes more vital every year so that the relief which may be afforded by hydrophone communication will, no doubt, be very welcome.

The use of powerful sound-sources, designed to be located off promontories, at harbor entrances, etc., and operated by power obtained from shore or installed upon light vessels will very materially increase the range at which such communication can be carried on or guiding bearings obtained, thus introducing the hydrophone into the field now occupied by the radio compass. One does not have to make many trips on the " trackless main " to appreciate the very positive value of each such additional source of information in situations of uncertainty and doubt.

On occasions when the radio is temporarily disabled, as for instance, when the antenna is carried away by a gale, the use of the hydrophone for communication purposes may be vital indeed.

THE HYDROPHONE AS AN ACCELERATOR OF COMMERCE.

Doubtless, the most fruitful aspect from a financial point of view of the advent of the modern hydrophone is its use in speeding up commerce. When one considers the enormous loss in time and money which is occasioned by vessels being frequently obliged to lie idle when waiting for clear weather in order to enter or leave port or to otherwise navigate in restricted waters, it is at once evident that a device which will eliminate such delays needs little advertising. The aids thus afforded will soon cancel the expense of the installation and will subsequently pay high interest upon the investment.

The development of the art to date justifies the prediction that harbors and channels will be provided with suitable submarine sound beacons which will enable a vessel fitted with a hydrophone to safely navigate in such waters during thick weather.

EXAMPLES OF THE USE OF THE MV HYDROPHONE.

Having discussed some of the theoretical details of the MV hydrophone and having considered certain lines of its future development and application, it will now be of interest to relate a few actual experiences and results which have been obtained with various installations of this type of hydrophone upon certain ships of the U. S. Navy. These instances will serve to demonstrate the value of this device as an aid and safeguard to navigation.

U. S. S. VON STEUBEN.

Much use was made of the hydrophone installation on the *Von Steuben* during her several trips as a transport plying between New York and Brest. A particular instance will be cited.

Throughout one of her return trips cloudy weather was encountered, so that navigation was of necessity by " dead reckoning " methods without the aid of solar checks. Referring to the chart

given in Fig. 10, it will be seen that in the coastal waters south of New England the 100 fathom curve runs in a nearly east and west direction. It should also be noted that the shoaling inside of this

THE M-V HYDROPHONE
AS AN AID TO NAVIGATION.

CRUISE OF SUBMARINE   JULY 14th-19th 1919.
(1) SUDDEN SHOALS AT BOON ISLAND DETECTED—COURSE CHANGED.
(2) SUBMARINE BELL ON LT. SHIP PICKED UP—ENTERING PORTLAND.
(3) SUBMARINE BELL ON LT SHIP PICKED UP—LEAVING PORTLAND.
(4) CHECK ON COURSE AFFORDED BY FIFTY FATHOM CURVE.
(5) CHECK ON COURSE AFFORDED BY FIFTY FATHOM CURVE.
(6) APPROACH TO CAPE COD DETECTED—COURSE CHANGED
(7) SUBMARINE BELL ON POLLUCK RIP SLUE LT SHIP FIRST LOCATED
(8) SUBMARINE BELL ON POLLUCK RIP SLUE LT. SHIP LAST LOCATED
(9) SHOAL LOCATED—COURSE CHANGED.
(10) SHOAL LOCATED—COURSE CHANGED
(11) SHOAL LOCATED—COURSE CHANGED
(12) COURSE CHANGED AT PREDETERMINED POINT
(13) SHOAL LOCATED—CHECK ON COURSE
(14) COURSE CHANGED AT PREDETERMINED POINT—FINAL DEPARTUE
(15) BUOY DISCOVERED DIRECTLY ON COURSE 40 MILES FROM 14

U.S.S. VON STEUBEN APPROACHING NEW YORK APR. 18th 19

(16) ORIGINAL (DEAD RECKONING) COURSE OF VON STEUBEN.
(17) 100 FATHOM CURVE DETECTED SEVERAL HRS PRIOR TO CALCULATIONS
(18) HYDRO BEARING OBTAINED ON NANTUCKET LT SHIP
(19) COURSE CHANGED IN ACCORDANCE WITH HYDROPHONE DATA.
(20) NEW COURSE—SATISFACTORY.
(21) ORIGINAL COURSE PROJECTED—POSSIBLY DANGEROUS.
(22) FINAL APPROACH TO AMBROSE LT SHIP
(23)(24) COURSE OF BLAKELY—SOUNDING OVER FAVORABLE SEA BOTTOM

FIG. 10.

curve is comparatively slow, while outside of it the depth increases rapidly. This ocean plateau, which is crossed by all vessels entering or leaving New York for European or Mediterranean ports, is read-

ily detected by hydrophone soundings as a ship crosses it steaming at full speed. Computations had predicted that the *Von Steuben* would cross this 100 fathom curve in the vicinity of longitude 70:00 about 2 o'clock on a certain afternoon. It so happened that the *Von Steuben* was actually proceeding on a course indicated by (16) about 10 miles to the northward of the supposed position, so that she would accordingly arrive at this depth some little time prior to expectations.

The hydrophone operator, who was listening upon the apparatus during the morning, first heard faint sounds from his own ship's propeller, in a depth of about 450 fathoms, at 9:25 A.M. A rapid shoaling was subsequently observed and the 100 fathom curve detected at 9:45, position (17). At 10:15 the hydrophone gave the depth as 55 fathoms, which observation was checked by the handlead. At the same time, position (18), the submarine bell on the Nantucket lightship, distant 37 nautical miles, was heard and a relative bearing of 66 degrees obtained. Subsequent computations gave the value of 67.5 degrees, a close check. This hydrophone bearing together with the sounding data gave a satisfactory "fix" by virtue of which the course of the vessel was changed at (19) and a more satisfactory approach to Ambrose Channel made as shown (20) and (22).

It is worth noting that the original course of the *Von Steuben* projected (21) would have carried that vessel towards the Fire Island Shoals, where many unfortunate vessels have gone aground.

The Submarine Installation.

A submarine was equipped with electrical MV hydrophone lines and the writer participated in a test cruise on this vessel from New London, Connecticut, to Portland, Maine, and return, for the purpose of ascertaining the characteristics of this, the first MV installation of its kind to be made on a submarine. The course of the cruise is drawn upon the chart given in Fig. 10. The entire trip was made by surface running on the Diesel engines, the most unfavorable condition for long range listening. Prior to departure a sounding scale had been computed for the compensator in terms of

the base-line ($2L$) of the vessel. Accurate hydrophone soundings could be made at all times and these, as will be shown, were a very great aid in navigating.

During the first day's run from New London to Provincetown through the Cape Cod Canal, the weather was clear so that a close check upon the progress of the vessel could be kept by observation of beacons along the shore. Hydrophone soundings were made from time to time and these were seen to agree closely with the depths given on the chart, thus affording a check upon the computed scale. The same procedure was carried out during the second day when the trip was made across Massachusetts Bay to the port of Salem.

Departure from Salem was made in a heavy fog. After clearing Cape Anne a compass course was set for Boon Island, off the coast of York, Maine. This small island is rather peculiar hydrographically in that it consists of a small peak rising abruptly in a sea of fairly deep water. A continuous sounding watch was maintained until the hydrophone suddenly showed a very rapid shoaling of the water in the position marked (1). Warning was given just in time to enable the navigator to make out a buoy off the island which was passed at close range. Had it not been for these hydrophone soundings the locating of this small island would have been a more tedious and hazardous project in the thick weather prevailing. A course was then set for the Portland lightship; soundings were taken en route to check the progress of the submarine. The submarine bell on this lightship was picked up and located at position (2), something over a mile before reaching it. Further aid was also afforded by the hydrophone while passing Cape Elizabeth and entering the harbor.

The submarine left Portland two days later in a settled spell of thick weather. Taking a departure from the lightship a course was laid almost wholly by compass and hydrophone soundings. At many points along this route, such as are indicated by (4) and (5), sudden changes in the depth of water were very readily noted and afforded excellent checks upon the progress being made by the vessel—in this manner serving the purpose of the log. The shoaling water off the

tip of the cape was detected at position (6).   The course around the cape was then easily followed until the submarine bell on the Polluck Rip Slue lightship was picked up at position (7), range 4 miles, and contact made with it.

Darkness had now fallen and with it an extremely heavy fog, so thick that the bow of the submarine could hardly be seen from the conning tower.   It would, without doubt, have been possible to navigate the vessel through Nantucket and Vineyard Sounds, as was originally planned, with no great difficulty—as sounding and lightship bells would have given sufficient aid.   However, it was thought that numbers of silent fishing boats might be anchored in these waters, offering a risk of collision.   Accordingly it was decided to go out around these islands.   The numerous and extensive shoals to the south of Nantucket are well charted so that a course was laid out beforehand with certain turning and checking points at various well-defined shoals—(9), (10), (11), (12), (13), and (14).

Taking a departure from the Slue lightship, which was the last beacon to be seen during the night, this predetermined course was readily followed.   Hydrophone soundings proved to be thoroughly reliable; the various points indicated were located with ease, *so that the navigator, cruising at full speed through the fog and darkness, was certain of his position at all times and proceeded with complete confidence.*   When the last shoal, (14), was reached in the early morning the hydrophone watch was interrupted and a compass course was set for (15), a buoy off No Man's Land, nearly 40 miles distant.   About 9:00 A.M. the fog suddenly lifted; the island of No Man's Land was seen on the starboard bow, and a few hundred yards ahead was the buoy in question—less than a point off the course.

While this precise locating of the buoy after such a lengthy run from the Slue lightship out around the islands was perhaps to be partially attributed to the element of luck, nevertheless, all on board considered that this result showed conclusively the aid to navigation which a hydrophone equipment of this type is capable of furnishing, due to its ability to give reliable soundings while the vessel continues undelayed on her course.   The trip, in spite of—or perhaps because of—the bad weather, was voted a complete success.

U. S. S. BLAKELEY.

The U. S. Destroyer *Blakeley* is equipped with an "acoustic-blister" type of MV hydrophone which has been used continuously for navigational purposes during the past year and has proved to be very reliable and advantageous. Two instances will be cited:

In June, 1919, the *Blakeley* was ordered to leave Philadelphia and to rendezvous with four other destroyers five miles south of Nantucket lightship. Upon clearing the Delaware Capes a heavy fog was encountered which held during the entire run to the Nantucket lightship. Difficulty was encountered in attempting to obtain "fixes" by means of radio compass bearings from shore stations, but at a distance of 12 miles the Nantucket lightship submarine bell was located and, by virtue of hydrophone bearings taken on this bell, an accurate position 3 miles south of the lightship was reached and a departure made for the Azores without sighting the lightship. During the fog and while in the vicinity of Nantucket, the propeller sounds of another vessel were picked up by the hydrophone at a bearing dead ahead. The course of the *Blakeley* was changed and the shift in bearing of the other vessel, which was not sighted, was followed until the assurance was given that she was well clear.

While en route from Pensacola to New York the *Blakeley* passed Hatteras during a certain forenoon in December, 1919, and laid a course to make a landfall on Barnegat Light. Before reaching this light, however, the vessel ran into a heavy fog and nothing was sighted until the Ambrose lightship was picked up about 8:00 A.M. the following morning. From the time the fog was first encountered the position of the *Blakeley* was checked by constant hydrophone soundings. A definite "fix" for latitude was obtained in crossing the deep water gulley off the entrance to New York harbor and the submarine bell of Ambrose lightship was picked up at a distance of about 7 miles, whence the ship's course was laid from bearings obtained on the hydrophone until the lightship was brought within sighting distance close abeam. The hydrophone could be relied upon to give warning of the approach of steamers from ahead and 15 knots speed was therefore maintained through the fog.

U. S. S. Breckinridge, Sounding Data Over Jagged, Uneven
Sea-Bottom.

During the month of January, 1920, while making a trip from
Charleston to Key West on board the U. S. Destroyer *Breckinridge,*
the writer had an opportunity of testing the utility of the MV hydro-
phone for sounding purposes under very adverse conditions. The
Breckinridge had been fitted with an electrical MV hydrophone, the
lines of which were installed in tanks built in the bottom of the
vessel near the bow. The tests were made over a period of 10
hours while the *Breckinridge* was proceeding down the coast on a
course which ran in part along the edge of the continental shelf, so
that the bottom was very uneven and erratic, and pronounced
changes in depth occurred. Two successive casts of the hand-lead,
made not more than one minute apart and taken with the vessel
moving less than five knots, frequently showed a discrepancy of
from 5 to 6 fathoms.

Time.	Chart Soundings.	Hand Lead.	Sounding Machine.	Hydrophone.	Position.	
					Latitude.	Longitude.
0900	12	—	14	14	32–20 N.	79–48 W.
0930	17	17¼	10	16	32–07	79–51
1000	19	21	20	20	31–55	79–54
1030	21	—	65	21	31–30	79–56
1100	24	30	35	21	31–30	79–59
1130	25	31	30	31	31–17	80–02
1200	26	31	30	27	31–05	80–05
1230	25	27	25	25	30–54	80–07
1300	25	31	26	26	30–44	80–09
1330	30	—	34 ?	29	30–33	80–11
1400	25–100	45	42	37	30–22	80–13
1430	25–50	46	46	46	30–11	80–15
1500	30	44	55	30	30–00	80–17
1530	26	32	38	22	29–49	80–19
1600	22	32	30	26	29–38	80–21
1630	17–23	28	23	21	29–28	80–23
1700	18	25	21½	18	29–16	80–25
1730	14	20	19	18	29–05	80–27
1800	11–12	17	13	13	28–54	80–29
1830	12	12¾	12½	13	28–44	80–27

At half-hour intervals soundings were made both by hand-lead
and the automatic sounding machine, the vessel of necessity being
slowed to about 3 knots for these operations. Just before stopping
and after starting the propellers soundings were taken upon the

FIG. II.
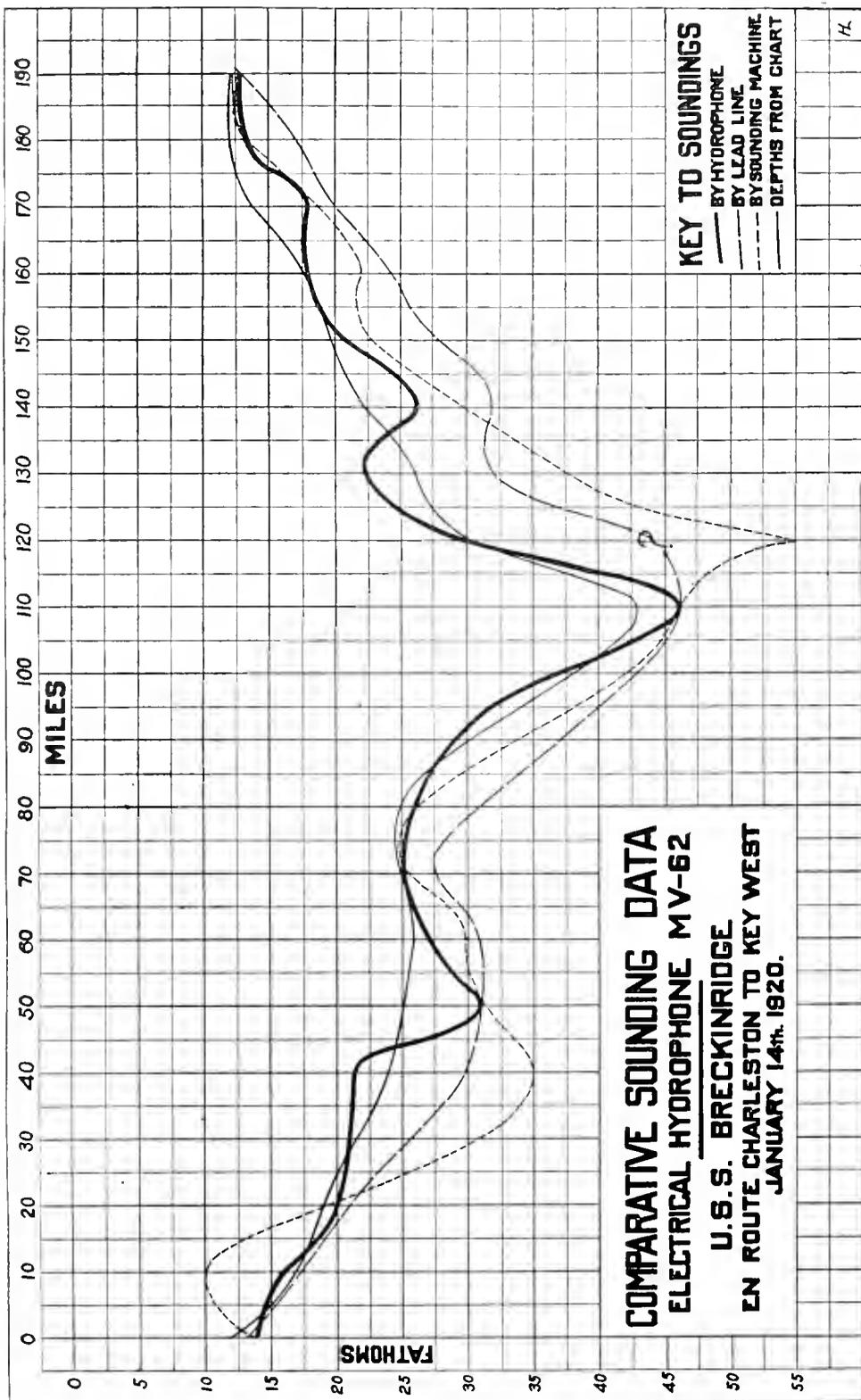
hydrophone in the usual manner. The depth was also noted as accurately as possible from the chart. These data are given below.

In order to show more clearly the variation between these different methods of sounding, the data have been plotted in Fig. 11 where the abscissæ represent distance travelled along the course and the ordinates the depth of water. Each of the four curves is a "sounding curve" taken by one of the four different methods as indicated in the key. These curves illustrate several interesting facts. In the first place, in spite of the discrepancies between the various values evident at certain places, it will be seen that, when two or more of the other methods do agree we find that the hydrophone sounding coincides with this point also. It should further be noted that the discrepancy between the hand-lead and the automatic sounding machine is, in general, quite as great as that between one or the other of these instruments and the hydrophone. Again, it is important to note that over the whole course the hydrophone soundng curve agrees most closely with the sounding curve taken from the chart. This fact shows that the hydrophone has a tendency to smooth out the local irregularities of an uneven bottom and to give an integrated mean curve which checks well with that obtained from the hydrographic charts. The depths given on the charts were obtained by taking an average of a number of soundings made in a given locality, thus canceling the local variations which are very prominent in this region. An illustration of this is to be seen on the 120-mile ordinate of the plot where the hydrophone and chart soundings agree, while the sounding machine evidently fell into a ravine, the bottom of which never was reached by the hand-lead. The greatest discrepancy (12 fathoms) between hydrophone and chart which occurred at 50 miles and whereat the sounding machine and lead checked the hydrophone evidently indicates a depression which was not noted on the chart.

The U. S. Blakeley, Sounding Data Over Favorable Sea-Bottom.

The curves in Fig. 12, plotted from data taken on board the U. S. S. *Blakeley* during a run from Block Island out to the 100

KEY TO SOUNDINGS
BY HYDROPHONE
BY LEAD LINE
DEPTHS FROM CHART

COMPARATIVE SOUNDING DATA
ACOUSTICAL HYDROPHONE MV-16B
U.S.S. BLAKELEY — 150
CRUISING OFF MONTAUK POINT
MAY 27th. 1920.

HOURS
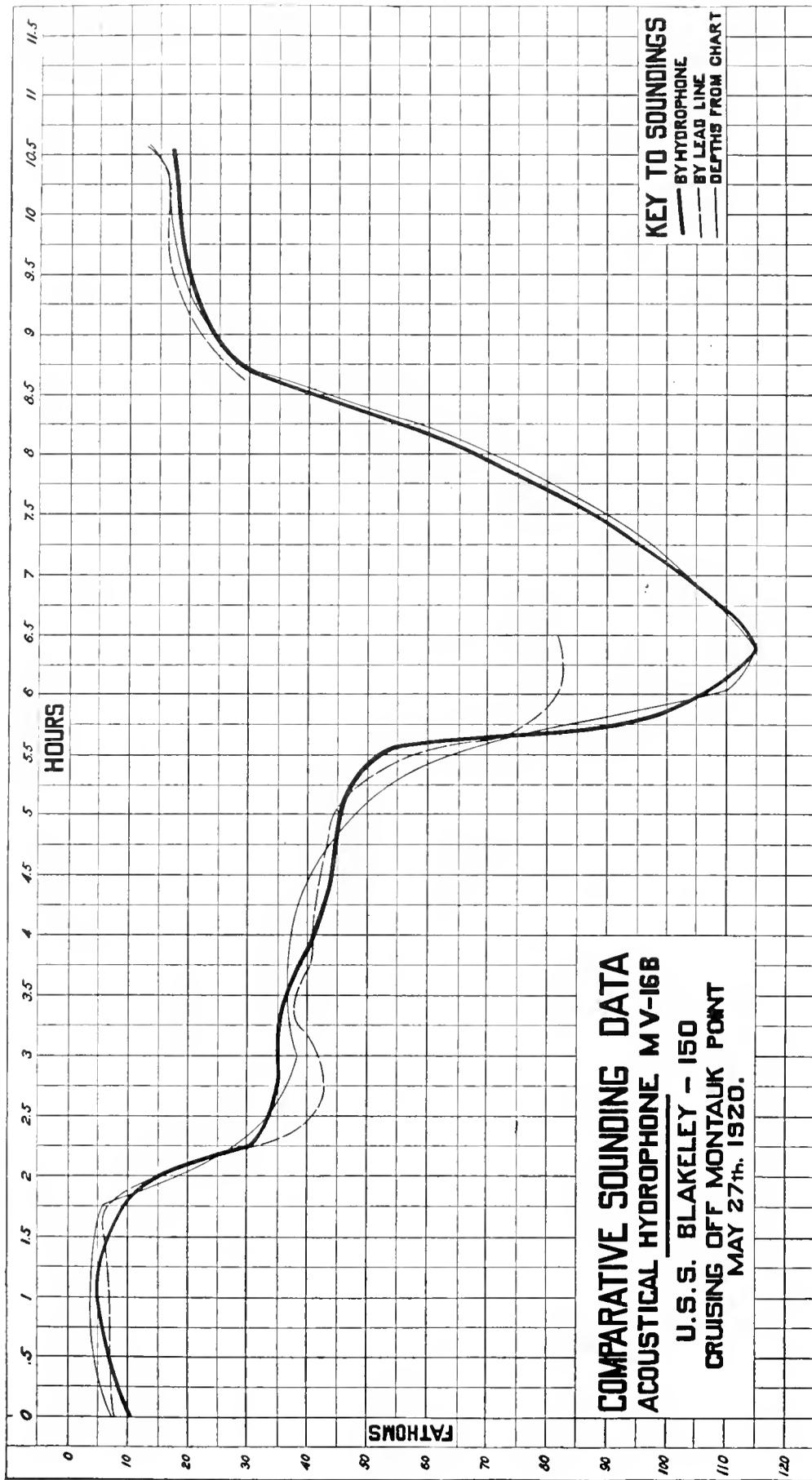
FATHOMS

FIG. 12.

fathom curve and back again into Newport Harbor, give some idea of the accuracy with which the MV hydrophone gives soundings over a favorable sea-bottom. (This course is laid off on the chart of Fig. 10.) Unfortunately the sounding machine broke down at the start, so the comparison data is not as complete as that taken on board the *Breckinridge*. The deep sea lead, however, was provided with a sounding tube which operated on the Kelvin principle and for depths beyond 10 fathoms the soundings were taken from this tube and not from the amount of line let out.

It is to be noticed that the hydrophone sounding curve (represented by the heavy full line) agrees very closely with the curve representing charted depths (light full line) except for the shoal area near Block Island. Here, however, the agreement with the soundings taken by the hand lead is almost perfect. The hand lead soundings in this region were taken with great care and there is no doubt in the minds of the experimenters but that the charted depths are about 2 fathoms too small.

The sounding tube seemed to function badly for depths beyond 50 or 60 fathoms and indicated little or no change for depths beyond 80 fathoms. At first it was suspected that the charted values were in error at the greater depths but the fact that the hydrophone soundings agreed closely with the charted depths and that the supposed position of the *Blakeley* checked perfectly on the return trip led all concerned to the belief that the charted depths are correct and that, on the whole, the soundings taken by the hydrophone are more reliable than those given by either the sounding tube or the chart.

Conclusion.

The MV hydrophone is the result of two years of intensive research work carried out by the Navy. It was developed as an instrument of warfare at a considerable cost and those best qualified to make such estimates claim that this expenditure is but a small per cent. of the saving to the Allied Powers which the hydrophone affected during the period of the war.

During the past year the Navy has discovered that the same qualities that enabled the MV hydrophone to detect and accurately

determine the direction of a submerged submarine enables it to serve as a powerful aid in safeguarding navigation in times of peace, and it is the confident belief of those most familiar with its operation that this device is destined to save more vessels and lives than were destroyed during the war by the U-boats that brought about its development.

ENGINEERING EXPERIMENT STATION,
    U. S. NAVAL ACADEMY,
        ANNAPOLIS, MD.

MAGELLANIC PREMIUM

Founded in 1786 by John Hyacinth de Magellan, of London

1921

THE AMERICAN PHILOSOPHICAL SOCIETY

Held at Philadelphia, for Promoting Useful Knowledge

announces that in

DECEMBER, 1921

it will award its

MAGELLANIC GOLD MEDAL

TO THE AUTHOR OF THE BEST DISCOVERY, OR MOST USEFUL INVENTION, RE-LATING TO NAVIGATION, ASTRONOMY, OR NATURAL PHILOSOPHY (MERE NATURAL HISTORY ONLY EXCEPTED) UNDER THE FOLLOWING CONDITIONS :

1. The candidate shall, on or before November 1, 1921, deliver free of postage or other charges, his discovery, invention or improvement, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A., and shall distinguish his performance by some motto, device, or other signature. With his discovery, invention, or improvement, he shall also send a sealed letter containing the same motto, device, or other signature, and subscribed with the real name and place of residence of the author.

2. Persons of any nation, sect or denomination whatever, shall be admitted as candidates for this premium.

3. No discovery, invention or improvement shall be entitled to this premium which hath been already published, or for which the author hath been publicly rewarded elsewhere.

4. The candidate shall communicate his discovery, invention or improvement, either in the English, French, German, or Latin language.

5. A full account of the crowned subject shall be published by the Society, as soon as may be after the adjudication, either in a separate publication, or in the next succeeding volume of their Transactions, or in both.

6. The premium shall consist of an oval plate of solid standard gold of the value of ten guineas, suitably inscribed, with the seal of the Society annexed to the medal by a ribbon.

All correspondence in relation hereto should be addressed

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PHILADELPHIA, U. S. A.

PROCEEDINGS

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

Vol. LIX.	1920.	No. 6.

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PHILADELPHIA

THE AMERICAN PHILOSOPHICAL SOCIETY

104 SOUTH FIFTH STREET

1920

The American Philosophical Society

announces that an award will be made in the year 1921 of the

HENRY M. PHILLIPS PRIZE

The subject upon which essays are to be submitted is

The Control of the Foreign Relations of the United States : The Relative Rights, Duties, and Responsibilities of the President, of the Senate and the House, and of the Judiciary, in Theory and in Practice.

The Essay shall contain not more than one hundred thousand words, exclusive of notes, and must be in the possession of the Society on or before December 31, 1920.

The Prize for the crowned essay will be Two Thousand Dollars, in gold coin of the United States, to be paid as soon as may be after the award.

Attention is called to the following regulations governing the award of the Prize:

Competitors for the prize shall affix to their essays some motto or name (not the proper name of the author, however) and when the essay is forwarded to the Society it shall be accompanied by a sealed envelope containing within the proper name and address of the author and on the outside thereof the motto or name adopted for the essay.

At a stated meeting of the Society in pursuance of the advertisement, all essays received up to that time shall be referred to a Committe of Judges, to consist of five persons, who shall be selected by the Society from nominations made by the Committee on the Henry M. Phillips Prize.

Essays may be written in any language, but, if not in English, must be accompanied by an English translation.

No essay which has been already published or printed, or for which the author has received any prize or profit of any nature whatsoever, shall be accepted in competition for the prize.

Essays must be typewritten on only one side of the paper, and six copies must be furnished by their respective authors for the use of the Committee of Judges.

The literary property of such essays shall be in their author, subject to the right of the Society to publish the crowned essay in its " Transactions " or " Proceedings."

The Society reserves the right not to award the prize if none of the competing essays is deemed worthy of it.

JOHN BASSETT MOORE,
DAVID JAYNE HILL,
SIMEON E. BALDWIN,
JOHN CADWALADER,
W. W. KEEN,
WILLIAM B. SCOTT,
President ex-officio,

Committee.

The essays must be sent, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A.

INTERRELATIONS OF THE FOSSIL FUELS.*

IV.

By JOHN J. STEVENSON

(Read March 5, 1920.)

The Paleozoic Coals.

In a great part of the areas, where deposits of Permo-Carboniferous age are exposed, the passage from Triassic is gradual; at most, the plane of contact shows only petty discordance of stratification. But in many extensive areas, the succession is incomplete and one or more members are missing, so that the Triassic may rest on any formation from Archean to Permian. In like manner, where the succession is complete, the Permian may pass downward into the distinctly Carboniferous so gradually that no definite boundary can be determined stratigraphically or by aid of changes in plant or animal life. At times, deposits assigned to the Permian rest on pre-Carboniferous rocks; at others, there is distinct discordance between Permian and Carboniferous, while in vast areas the succession is apparently conformable throughout. Lithological changes usually occur in the upper part of the section; at one time, the presence of red rocks was considered proof that Permian had been reached. This opinion is not final, in many regions red beds occur in distinctly Carboniferous deposits. Frequently, the basal portion of the Permian contains conglomerates, holding pebbles, striated seemingly by glacial action.

The problem of the relations between Permian and Carboniferous coal measures is vexatious to the last degree, as the testimony of stratigraphy, paleontology and paleobotany seems to be in conflict. In some cases, the conflict is not real, but in others it is a

* Part I appeared in these *Proceedings*, Vol. LV., pp. 21-203; Part II. in Vol. LVI., pp. 53-151; Part III. in Vol. LVII., pp. 1-48.

fact and it can be removed only by revision of conceptions, which have become laws, because accepted for a long time.   But questions of nomenclature and relations have only incidental importance in connection with matters under consideration in this work.   The term Permo-Carboniferous will be employed here, as it has been accepted by many students; it renders unnecessary all discussion as to propriety of regarding the Permian as more than a subordinate division of the Carboniferous.

PERMO-CARBONIFEROUS COALS.

Australia.

Queensland.—Jack and Etheridge[1] include under the name Permo-Carboniferous, the rocks between Devonian and Trias-Jura and divide them into the Star, Gympic and Bowen formations.

The Star and Gympic yield a flora of distinctly Carboniferous type; the fauna is marine and certainly allied to that of the Lower Carboniferous.   The relations of these formations to each other were not determined, as they occur in isolated areas; they have *Calamites, Lepidodendron, Cordaites* and eleven genera of inverte- brates in common, but a number of species are peculiar to the Star. *Lepidodendron* abounds in sandstones and some shales.   The Gympic beds are much disturbed, those of the Star, very little.

The Bowen, divided by Jack into Lower, Middle and Upper, had not been found in contact with the Lower Carboniferous up to the time when the report was prepared.   Lycopodiaceous plants are wanting, their place being taken, apparently, by the fern *Glossop- teris.*   The Lower Bowen has yielded no remains of animals and it is capped by a series of bedded volcanic rocks; the Middle is rich in mostly marine mollusks and contains some remains of land plants; The Upper had abundance of land plants and one bed has marine mollusks like those of the Middle.   The Bowen is thought by Jack to be equivalent to the upper portion of the New South Wales Permo-Carboniferous.

The Lower Bowen, consisting of grits, sandstones, conglomerates

[1] R. L. Jack and R. Etheridge, Jr., "The Geology and Palæontology of Queensland, etc.," Brisbane, 1892, pp. 3, 70, 135, 141, 147–159, 161–171.

and shales, contains remains of reed-like plants with fragments of silicified wood in the sandstones and shales; black shale with highly carbonaceous bands was seen at one locality, but no coal was discovered anywhere. The Middle or marine Bowen, composed of yellow to gray sandstone, with blue to yellow-gray shales and some ferruginous bands, is remarkably rich in mollusks, some of which belong to Permian types. Vertical rootlets in shales and sandstones are taken by Jack to indicate occasional recurrence of land surfaces. Silicified trunks of trees, prostrate, were seen in sandstone at several localities. Only two coal seams were recognized; the Kennedy, of merely local importance, is about 2 feet thick, double or triple, and rests on a floor containing vertical rootlets; the Garrick, higher in the formation, and 4 feet 9 inches thick, shows near the bottom a light lustrous coal in nodules of 3 to 4 inches diameter. The coal in the main portion of the seam yields a bright, hard coke but coke from the nodules is spongy. The floor is soft sandstone and contains rootlets; the prevailing plants are *Sphenopteris* and *Glossopteris*. The Upper Bowen, including many sheets and dikes of diorite, consists of gray shales and greenish-gray sandstones with some conglomerate. The Daintree coal seam, near base of the formation, is exposed in the bed of Bowen River, where it is less than 10 feet below a mass of diorite. The section is (1) Burnt coal, partly columnar, contains *Glossopteris,* 3 feet 7 inches; (2) black shale, 1 inch; (3) burnt coal, 3 inches; (4) stony burnt coal with silky plant débris, 6 inches; (5) light, porous, crumbling coal, with concretionary nodules of better coal, 8 inches; (6) blue-black shale, 2 feet 3 inches; (7) light brownish-black, laminated coal, with laminae of oil-shale, 7 feet; (8) blue-black shale, 2 feet 3 inches; (9) good coal, 3 inches; total, 17 feet 5 inches. The influence of the diorite sheet disappears at about 15 feet. The McArthur seam, higher in the section, is in 5 benches with a total thickness of 12 feet 3 inches, but the coal is only 5 feet and has 32 per cent. of ash. The sandstones above this coal contain large stems of drifted coniferous trees, which are silicified and, at times, retain some of their roots. A third seam, unimportant, is near the top of the formation and only a few feet below red sandstone with a marine fauna.

The Bowen coals are inferior; those of the Middle have from 11

to almost 17 per cent. of ash, while those from the Upper have from 14 to 38. Great variation occurs in a single seam; anthracite at one place, 4 feet 4 inches thick, has at one mine only 3.5 per cent. of ash, whereas in another it has 23.61. No igneous rocks were seen in the neighborhood.

New South Wales.—The Permo-Carboniferous, according to David,[2] is divisible within the Hunter River region into

The Newcastle Series, freshwater, with coal seams....... 1,400 to 1,500 feet
The Dempsey Series, freshwater, no workable coal...... 200 to 2,000 feet
The Tomago Series, with coal seams................. 1,600 to 1,800 feet
The Upper Marine Series, without coal................. 5,000 to 6,400 feet
The Greta Series, with coal seams.................... 150 to 300 feet
The Lower Marine Series, with little coal............. 4,800 feet

A great gap exists between Carboniferous or "Gympic" deposits, which, most probably, belong to the Lower Carboniferous. On the border of Queensland, in the Ashland coal field, the Permo-Carboniferous rests in great unconformity against the Lower Carboniferous, which is not far from 20,000 feet thick. This vast mass consists, in the lower and middle divisions, of marine beds, but the upper division is mostly lava and volcanic tuffs. The gap is indicated not only by the angular unconformity but also by the fact that but one genus of plants is common and the contrast in fauna is almost as great.

The Lower Marine Series has, at base, a deposit about 200 feet thick, underlying a basalt sheet and containing many glaciated pebbles. The first appearance of *Gangamopteris* is at about 3,000 feet from the base; and at 500 feet higher is a coal seam of rather inferior quality, 10 feet 6 inches thick, inclusive of the partings which contain *Gangamopteris*. The Greta Series, sandstones and shale, has near the base the Homeville seam, 3 to 11 feet 6 inches thick, hard, bituminous coal; at the South Greta mine it rests on Kerosene shale. At 50 feet higher, the interval being filled with sandstone, conglomerate and shale, is the Greta seam, 14 to 32 feet thick, with floor of shale and roof of sandstone or conglomerate. Where the

[2] T. W. E. David, "The Geology of the Hunter River Coal Measures, New South Wales," *Mem. Geol. Survey of New South Wales,* No. 4, 1907, pp. 311–327, 354.

roof is sandstone, marine fossils are present at a little way above the coal. Locally, owing to increase of the alga, *Reinschia australis,* it passes over to cannel or even to Kerosene shale. The coal seams of this series divide toward the north, which David takes to be wholly normal; the Carboniferous had been elevated to form highlands on that side, so that the quantity of transported material increased in that direction. The Tomago Series, sandstones, conglomerates and coal seams with beds of iron ore, has six workable seams, which yield excellent coal but too friable for shipment, being inferior in that respect to coal from the Greta and Newcastle. The Newcastle Series has many coal seams of high grade and great persistence. This series is notable because of abounding *Vertebraria* in the floor and of *in situ* tree-stems in the roof of coal seams.

Wilkinson,[3] many years ago, separated the deposits into Upper and Lower Carboniferous. The latter has marine fossils in many beds, while in others *Lepidodendron, Sigillaria* and *Calamites* abound, but workable coal seams are unknown. This is equivalent to the Lower Marine Series of the Hunter River field. The Upper Carboniferous has, below, the important seams at Greta and East Maitland, separating the two Marine Series. The plants are species of *Glossopteris, Phyllotheca, Noeggerathia* and *Annularia. Phyllotheca* and *Glossopteris* occur on slabs, associated with characteristic fossils, which McCoy, de Konninck and others have recognized as Carboniferous. The Upper Carboniferous had been referred to the Permian, but Wilkinson accepted this as only a provisional reference. The characteristic plants are *Glossopteris, Gangamopteris, Vertebraria, Phyllotheca* and *Sphenopteris,* but marine shells appear to be wanting. This upper division is evidently equivalent to David's Tomago, Dempsey and Newcastle. The *Glossopteris* of New South Wales is of interest because of the memorable controversy between McCoy and Clarke,[4] in which the former maintained that the presence of this plant proved Mesozoic age for the deposits, because in India it occurs in Oolitic rocks, whereas the

[3] C. S. Wilkinson, " Notes on the Geology of New South Wales," Sydney, 1882, pp. 44, 45, 51.

[4] W. B. Clarke, " Remarks on the Sedimentary Formations of New South Wales," in Mines and Min. Statistics of New South Wales, 1875, contains a history of this dispute. pp. 161 et seq.

former asserted that the fauna was absolute proof of Paleozoic age. It may be well to recall that this fauna reappears in Queensland at top of the Bowen formation.

According to Mackenzie,[5] the coal seams of the upper measures are much broken by partings, usually thin. The seams, at times, are thick, 8 to 26 feet, but much of the coal is poor. A faux-toit, consisting of coarse coal and "coal and bands," 4 to 12 feet thick, is present at many localities. The benches frequently differ in character of the coal. The roof and floor are usually shaly clay and in most cases the roof is plant-bearing. The coal seams of the lower coal group are much divided and show great difference in the several benches. Occasionally the underclay is crowded with *Vertebraria*.

The lens shape of coal seams is a by no means rare feature. The important seam at Greta suffices for illustration.[6] At the Greta mine, it has 6 benches, including one of Kerosene shale, and is 26 feet thick, inclusive of 6 feet of partings and inferior coal; but within 32 chains it becomes only 17 feet 6 inches, while at three miles north it is but 7 feet 6 inches and the Kerosene shale is wanting. That shale occurs as lenticular deposits with the seams, and bears close resemblance to cannel in mode of occurrence. Liversidge[7] states that at Joadja Creek this mineral contains *Glossopteris* and *Vertebraria*. The fronds of the former usually are spread between the laminæ but the latter crosses them.

David[8] says that the Stony Creek and Greta coal measures, underlying the Upper Marine Series, are thin at the south but become thicker northward, the increase being due to splitting of an important coal seam into several thinner ones. At East Maitland, he saw in the East Maitland (Tomago) series a coal seam, consisting of an upper division, clays and coal, 4 feet, and a lower division, coal and thin partings, 4 feet. At little way northward, the divisions have become distinctly separate seams and, at another locality farther north, the interval between them is 140 feet. In a later report, he

[5] J. Mackenzie, "Mines and Mineral Statistics," pp. 209–243.

[6] Annual Rep. Department of Mines, 1883, p. 149.

[7] A Liversidge, "Description of the Minerals of New South Wales," Sydney, 1882, p. 160.

[8] T. W. E. David, Ann. Rept. Dept. of Mines for 1887, pp. 147, 149, 151; the same for 1890, p. 229.

notes his discovery of *Glossopteris* leaves in closely matted layers within a soft fireclay. They were undecomposed, were not brittle or carbonized, but retained the original substance. Soaked in glycerine and water, they could be unrolled and laid out flat. A large number of the specimens were mounted and placed on exhibition in the Museum of the Department of Mines.

More than forty years ago, Wilkinson stated that "on the coast, near the Nobby, Newcastle, may be seen several trunks of trees up to one foot thick, with roots attached, starting from a seam of coal and embedded in the strata in the upright position in which they grew." In the interval since Wilkinson studied the region, detailed examinations have been made and the conditions have been presented by David[9] in his remarkable memoir on the Hunter River. It will suffice here to cite only the description of features observed in the Newcastle or highest Series. That contains 12 seams, which are workable in more or less extensive areas and occur in two divisions, separated by a thick deposit containing much diagonally-bedded conglomerate in great lenses. The color of this mass is greenish- to reddish-brown.

The Wallarat or Bulli seam, at top of the Permo-Carboniferous, directly underlies the Trias and is much eroded; its underclay is a root-bed. The Great Northern seam, 14 feet thick and 120 feet lower, underlies conglomerate and is much eroded at the junction. The conglomerate, at base, holds flattened stems of trees. At the cliffs of Catherine Hill Bay, the top of this seam has numerous stumps of large trees and the underclay has vertical *Vertebraria*, separated by intervals of about 2 feet   Below the floor of this coal seam is the Fennel Bay fossil forest, which is persistent in the Newcastle Series at 20 to 80 and 100 feet below the Great Northern. These plants are *in situ*. At somewhat more than 200 feet below the Great Northern the lower Pilot seam is reached, 5 feet thick and 33 feet below the upper Pilot, the interval being filled with tufaceous beds. The top portion of the lower seam, splint coal, has great numbers of vertical trunks and stumps, rooted in the coal, in some cases 30 feet high, reaching to the floor of the upper bed.

[9] T. W. E. David, "Geology of the Hunter River Coal Measures," pp. 3–41, 330–332.

This upper bench of the lower Pilot is a network of long straight roots radiating from the stumps.   David recognizes that the tuffs must, have accumulated rapidly as, otherwise, the stems would have rotted away.   This roof forest is well shown on French Bay of Lake Macquarie.   The tree stems are chalcedony above the coal, but in the coal they are a hydrocarbon.   They are 10 to 15 inches thick and are about 5 yards apart.   Drops of resinous matter, distilled from the broken branches, are present in tuff surrounding the stems, such as one finds in recent tuffs within the Andes region.   The lower bench of the bed has numerous stems and vertical roots, which David conceives may be the remains of another fossil forest.   The under clays of both Pilot seams have abundant *Vertebraria,* while some partings have *Vertebraria* and *Sporangia.*

The Burwood seam, 13 feet thick inclusive of partings, gives evidence of contemporaneous erosion before or during deposition of the overlying shale.   The conglomerate above has rounded pebbles of coal, one to three inches diameter.   David is inclined to believe that these came from the Burwood seam, though he grants that the source may have been one of the Greta seams. . They are proof that when the conglomerate was deposited coal, already hard, existed. *Vertebraria* abounds in underclays of coals in the lower division and stumps, *in situ,* were seen in the roof of several seams.   A gravel bank, 70 feet thick and one fourth to one half mile wide, marks the course of an ancient erosion.   The vertical stems, in all cases, are conifers.

In summing up the facts, David state that the floor of each seam contains abundance of *Vertebraria* (the root of *Glossopteris*), while the roof shows more or less well preserved stumps of *in situ* trees. The lower part of stumps and roots, where they form part of the coal seam, still retain a large proportion of the original carbon and only the upper part has become slightly silicified.   But the tree stump, where extending a few feet above the coal seam, is completely silicified, changed into chalcedony, but the minute tissue is usually preserved.   Where the woody portions are replaced with carbonate of iron, retaining the woody structure, the bark, one or two inches thick, has become brittle, bright bituminous coal.   This leads him to suggest that the bright laminæ of the coal were made

from bark of coniferous trees and that the dull, splinty laminæ, containing a notable proportion of mineral charcoal, were derived from *Glossopteris* stems and leaves. Sporangia abound but not in quantity to give spore coal.

The prevalence of *Vertebraria* makes probable that the peaty swamps, now represented by the coal seams, began as fern brakes with reeds. He had never seen a tree stump in the underclay. The swamps at length became Waldmoors, covered with Dadoxylon forests. These, at several horizons, were overwhelmed by showers of volcanic dust and drops of resin were preserved in considerable quantity within this dust.

Cannel occurs as lenses within the thick Greta seam; the oil shale or Hartley mineral occurs in like manner as lenses within the coal, These, at times, are of considerable lateral extent and occasionally that mineral forms a more or less persistent bench, in which the richness varies greatly. The character of coal is rarely the same throughout a seam, cannel, splint and bright bituminous being found frequently in the section of a single seam.

India.

The Permo-Carboniferous of India is exposed in isolated fields, large or small, within a strip, crossing Hindostan between parallels 19 and 24. These deposits, belonging to the Lower Gondwana, are divided into the Panchet, Raniganj, Barakar and Talchir, of which Panchet has been referred to the Trias. The Raniganj and Barakar are equivalent to the Upper and Lower Damuda and, in much of the region, are separated by a mass of clayey to sandy and carbonaceous shale, holding much clay iron stone. Coal is confined practically to the Damuda beds, there being only occasional carbonaceous shale and local seams in the Talchir. This lowest member consists of greenish, at times sandy or gravelly muds, frequently containing pebbles and large blocks of rock, so that, in places, there is a distinct bowlder bed. The variations of the Permo-Carboniferous can be made clear by examination of several fields from east to west.

The *Rajmahal* fields is northeast from Calcutta between the

Ganges and Dwarka Rivers. Ball[10] reports that the Talchir has no coal but has *Gangamopteris*. The Barakar, in the northern part of the area, consists of coarse, friable, feldspathic grits with white argillaceous shales and a few seams of inferior coal. False-bedded sandstones occur near the coals.

The *Jheria* field[11] is on the northerly side of the Damuda River and its easterly boundary is about 170 miles above Calcutta in Bengal. The Damuda and Talchir are not far from 6,800 feet thick. The Raniganj, largely sandstone, seems to be without coal, and the same condition marks the Talchir. Some carbonaceous shale in the latter has ill-preserved remains of plants, among which is a form closely allied to *Glossopteris*. The Barakar, consisting of clayey, sandy or carbonaceous shales and shaly sandstones, with grits and sandstones in the basal portion, has coal seams in all portions; but these are thickest in the coarse lower part. At all horizons, these are variable in thickness of coal and of partings; pyrite is abundant and the quantity of mineral matter renders the coal almost worthless.

On the Chat Kurree Jour, some seams are very thick; Hughes noted thicknesses of 50, 6, 5, 8, 13 feet. The thickest deposit is at the base and is a mass of shale and bad coal; but there is one seam, almost 5 feet thick, which is fairly good bituminous coal with only 11 per cent. of ash. Concretionary nodules were seen at several localities; the laminæ of the enclosing coal cross the concentric laminæ; the nodular coal is better than the enclosing material. The characteristic plants are *Glossopteris* and *Vertebraria*; no marine fossils were observed but there are freshwater limestones with *Melania, Paludina* and *Planorbis*. The seams are extremely irregular and appear to be of limited horizontal extent. Hughes is confident that the absence in so many places cannot be due to faulting and that the only explanation is that they are merely local deposits.

The *Raniganj* field is west from the Jheria and 120 to 160 miles northwest from Calcutta. There Blanford[12] found the Talchir rest-

[10] V. Ball, "Geology of the Rajmahal Hills," Mem. Geol. Survey of India, Vol. XIII, 1877, pp. 155–248.

[11] T. Hughes, "The Jheria Coal-Field," Memoirs, Vol. V., 1866, pp. 227–236.

[12] W. T. Blanford, "On the Geological Structure and Relations of the Raniganj Coal-Fields," *Memoirs*, Vol. III., 1865, pp. 1–195.

ing on gneiss. It has a bowlder bed on top and its shales and sand-
stone often have rippled surfaces as well as obscure impressions,
suggestive of footprints. No coal was seen and the plants, which
are not abundant, belong mostly to *Glossopteris* and *Cyclopteris.*
The Lower Damuda (Barakar) has coarse to conglomeratic white
sandstone at base, succeeded by coarse, micaceous shaly sandstone
with seams of coal and shale, often thick. "These seams are ir-
regular both in thickness and in quality; they frequently disappear
entirely or pass into shale or even sandstone within short distances."
The Lower Damuda is about 2,000 feet thick, a notable decrease
from the Jheria field, where it is about 3,300. The ironstone
group, overlying the Lower Damuda, is about 1,200 feet thick and
contains no coal. The Upper Damuda (Raniganj) consists of sand-
stone and shale without conglomerate; its coal seams are less irregu-
lar than those of the Barakar. The whole of the Lower Gondwana
to the top of the Panchet is practically conformable, the apparent
lack of conformity at some localities being due to overlap.

The Barakar coal seams are, for the most part, poor in quality
but vary in that as well as in thickness. At one locality, in northern
part of the field, is a seam, 34 feet thick, with three benches of coal,
7, 14 and 11 feet, but the coal is poor and slaty except in one part
of lowest bench. This great deposit can be traced for only a short
distance and it thins away rapidly in all directions. Many thick
seams were seen west from Barakar River. "These seams, how-
ever, seldom appear continuous over the whole area of the field;
they can often not be traced for more than a few hundred yards and
the quality of the coal may (and in general does) vary within even
shorter distances." In one case a seam, 13 feet thick, divides into
two within 50 yards, and the lower division soon is replaced with
sandy shale. At times, sandstone and shale replace the coal for
considerable distances. "Ballcoal" is not rare and the concentric
laminæ are crossed by laminæ of the enclosing coal.

The Raniganj seams are less irregular and contain less shale.
Blanford saw one 22 feet thick which was without parting, but ordi-
narily there are two or more benches. As a whole, the coal of this
formation must be regarded as inferior; the 17 analyses show 8.50
to 35 per cent. of ash; only two samples had less than 10 and 6 had

more than 20 per cent. As the samples were clearly supposed to represent the average coal mined, they mark only the best and serve to indicate the general inferiority.

The *Aurunga* and *Hutar* fields are somewhat more than 100 miles west from the Raniganj field. There, according to Ball,[13] the Lower Gondwana is overlapped by the Machadeva or Lower Jura, which, west from the Aurunga River, rests on metamorphic rocks. There is no coal in the Talchir. Ball thinks that the Karharbari coals belong to the Talchir rather than to the Barakar, though the associated rocks are similar to those of the Barakar.

In the Aurunga field, the Barakar deposits are sandstone grits and conglomerates with huge seams consisting mostly of carbonaceous shale, which occur "at various horizons and with most irregular lateral expansion." The deposition was confused; overlaps are frequent; changes in character and thickness of individual deposits are abrupt; pebbly conglomerates pass into breccias. The Barakar is about 1,500 feet thick in this field and the coals are of inferior quality. In the Hutar field, the Talchir is overlain on the western side by conglomerates and sandstones, resembling those of the Lower Jura. Coal is present in the Barakar on the Dauri River and westward, but it is wanting east from that river. The great irregular seams are not here but, instead, there are thin seams, often yielding good coal; these are intercalated in the sandstones within a vertical space of about 200 feet.

In both fields, the Barakar overlaps the Talchir and the seams of coal and shale are often of notable thickness. In a section near Rajbar, only 271 feet long, Ball measured 9 seams, about 10, 12, 83, 7, 13, 13, 21, 12, 24 feet, consisting mostly of carbonaceous shale with many streaks of poor coal. A sample from one seam, which looked like good coal, had only 22 per cent. of fixed carbon but 50 per cent. of ash. Similar conditions exist on the Sukri River near Toobed, where two seams were seen, 77 and 36 feet thick. This coal zone thins away toward the southeast. A zone of rippled sandstone was seen near Toobed. In the Hutar field there are four seams, 1 foot 3 inches to 8 feet thick, with much carbonaceous shale

[13] V. Ball, "On the Aurunga and Hutar Coal-Fields," *Memoirs,* Vol. XX., 1880, pp. 1–127.

in each, but there is a greater proportion of good coal than in the Aurunga field. The ash in analyzed specimens is from 7.8 to 18.2 per cent., whereas in the Aurunga field it is 15 to.34 per cent. The rocks of the Hutar are as irregular as in the other field. The Raniganj consists chiefly of soft yellow false-bedded sandstone and contains a coal seam, one foot thick. Its coal has 2.5 per cent. of ash.

The *Ramkola* and *Tatapani* coal fields, west from the Hutar field, are part of a strip extending westwardly about 200 miles to Jabalpur on the Narbudda River and thence southeastwardly about 300 miles to near Sarbalpur on border of the Talchir field in Orissa. Griesbach[14] states that Talchir, very irregular in occurrence and filling hollows in the metamorphic rocks, consists of clays and sandstones with conglomerate at top. The extreme thickness is not far from 900 feet.

The Barakar, consisting largely of micaceous sandstone, often flaggy, often crossbedded, contains some variable coal seams, which occur in three zones, two midway in the formation and the other directly under the Raniganj. In one of the middle zones, he saw a seam, 7 feet thick, but within a short distance it is but 3 feet 6 inches, while farther west the horizon is represented by 17 feet of black shale with streaks of coal. This kind of variation seems to be characteristic of the Barakar coals. The formation is not more than 900 feet thick; its coal is practically worthless and much of it is lignitic. The Raniganj, about 1,200 feet thick, is made up of white feldspathic gritty sandstone and white shale. No coal has been discovered. The Barakar in this area is characterized by *Glossopteris communis, G. browniana, G. damudica* and *Vertebraria indica;* but the Raniganj has *G. communis, G. angustifolia* and *G. retifera.*

The *Wardha Valley* field is about 175 miles southwest from the last. It was examined by Hughes,[15] who found the Talchir and Barakar clearly defined but the ironstone shales and the Raniganj are indefinite; the term, Kamti, is applied to the rocks occupying

[14] C. L. Griesbach, "Geology of the Ramkola and Tatapani Coal-Fields," *Memoirs,* Vol. XV., 1880, pp. 129-192.
[15] T. W. H. Hughes, "The Wardha Valley Coal-Field," *Memoirs,* Vol. XIII., 1877, pp. 1-154.

the interval. Talchir, without coal, has the same features as in eastern fields; Feistmantel found fronds and seed vessels of *Ganga-mopteris,* which he separated from *Glossopteris.* This plant occurs also in the Barakar.

The Barakar is only 250 feet thick, whereas in the Jheria field it is 3,300. Coal is confined to a band near the top. At one locality, a boring pierced a seam, 48 feet thick, with 3 benches of coal, 30 feet, and 4 benches of coal and shale; coal taken from a bench 15 feet thick, proved to be good as fuel, but it splits on exposure and when wetted it crumbles. At another locality, the seam is almost 59 feet, with 44 feet of coal, but ash is almost 23 per cent., though there is some "less bad" coal in one portion with only 18. At still another locality, the seam is 81 feet, in two main benches, 37 and 32 feet. A specimen yielded 14.5 per cent. of ash. This mass, though generally thick, shows extreme irregularity and in many borings no trace of it exists. Hughes was not prepared to decide whether the explanation is to be found in erosion or in non-deposition, but was inclined to accept non-deposition, for many outcrops show the attenuated border of deposition, containing only shale with no disintegrated coal. The Barakar coal is bituminous, but, as a rule, it is inferior because high in ash and sulphur. No coal has been seen in the Kamti. No marine fossils have been discovered.

The southern part of the *Sátpura-Gondwána* Basin is about 140 miles north from the last and about 50 miles farther west. According to Jones,[16] the Talchir here is as in the fields at the east. Bara-kar coals are present in the numerous petty basins and the seams vary from a few inches to 11 feet; but the thicker ones are divided by clay partings. Occasionally, the coal has a sandstone roof. Mining is insignificant and there is nothing in the character of the coal to justify exploitation; analyses from six localities showed 17 to almost 49 per cent. of ash and only one specimen caked.

The Narbudda River reaches the Gulf of Cambay on the west coast of Hindostan near the 22d parallel; the *Narbudda District* is on the lower part of the river and is west from the Sátpura region.

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[16] E. A. Jones, "Southern Coal-Fields of the Sátpura Godwána Basin," *Memoirs,* Vol. XXIV., 1887, pp. 1–58.

In the central part of the district, Medlicott[17] grouped the Permo-Carboniferous into Talchir, Lower and Upper Damuda. The Talchir has the familiar features and at most is about 600 feet thick.

The Lower Damuda (Barakar and Ironstone shales) has an extreme thickness of not far from 1150 feet. The rocks are mostly sandstone and sandy shale, but there is a considerable proportion of black shales. At times, the sandstones are rippled and often are crossbedded. The deposition was irregular; sandstones pass to shale abruptly. *Glossopteris, Vertebraria* and *Phyllotheca* are abundant at several horizons. The coal seams, for the most part are thin and, with one exception, are without value, while, at best, they are mere lenses. The Upper Damuda (Raniganj), about 150 feet thick, is composed of irregularly bedded clays and clayey sandstones. The coals are thin and of indefinite extent. A section obtained at the junction of the Machariva and Sher Rivers and extending 150 yards, illustrates the conditions:

(1) Sandstone not measured; (2) good coal, 3 inches; (3) soft sandstone, 3 feet; (4) coal seam, consisting of black micaceous shale, 6 inches, coal 2 feet, shaly coal, 6 inches, in all 3 feet; (5) hard sandstone, 3 feet; (6) blue clay, 4 feet. The black shale of (4) is cut out quickly by (3) and the shaly coal of (4) disappears within a few feet, while (2) and (3) are replaced with clay before the end of the exposure has been reached. *Glossopteris* is wanting in the Upper Damuda, its place being taken by cycads. The coal seams are wholly unimportant.

The Talchir beds in the *Thilmille* coal field of Serguja have a thin seam of coal; but as a rule this formation is distinguished by absence of coal and even of carbonaceous shale. The Kharharbari coal group was included originally in the Barakar, but it was placed in Talchir by Medlicott and Blanford[18] because of the intimate relation of the flora.

In studying reports on the several coal fields one cannot fail to be impressed by the thinning of Raniganj, Barakar and Talchir from

[17] J. G. Medlicott, "On the Geological Structure of the Central Portion of the Narbudda District," *Memoirs,* Vol. XIII., 1877, pp. 155–248.

[18] H. B. Medlicott and W. T. Blanford, "Geology of India," Calcutta, 1879, pp. 109–112.

east to west; the apparent exception in the Narbudda district is only apparent, for Raniganj and Barakar are counted as one and the Panchet or Trias is the Upper Damuda. Equally noteworthy are the great irregularity and evidently local character of the coal seams, which are hardly less striking than the small proportion of high-grade coal in all of the fields.

Siberia.

Carboniferous deposits are exposed in broad areas within the Kirghiz Steppes of western Siberia.[19] There, according to the synopsis published by the Comité Géologique, the Lower Carboniferous rests at times on the Devonian, at others on the metamorphics. The lower portion is mainly limestone, but higher in the section the prevailing rocks are gray or green calcareous sandstone, with marine fossils similar to those of the limestone. This portion, however, varies greatly; in some localities it is chiefly shaly sandstone while in others it is mainly black clay shale.

Directly overlying the Lower Carboniferous is the Coal series, consisting of alternating white, gray to black, more or less sandy shale, with yellow to green and white clayey sandstones and some seams of coal. The white to gray sandstones occasionally become conglomerate, but only in limited areas. The only fossils are plants, which occur abundantly in the roof or near the coal; but these are ill-preserved and, in large part, only the genus can be determined; the flora, however, is distinctly Upper Carboniferous.

The coal-bearing rocks are in valleys, enclosed by older deposits and in most localities are greatly disturbed, though the disturbance is comparatively slight in a few areas. The variation in thickness of coal seams is almost as notable as in those of India. Borings made near Ekibas-touz, under supervision of the government geologists, revealed the presence of two seams, 23 and 40 meters along a line of 7 versts; but elsewhere the total of coal rarely exceeds 6 meters and, too often, the seams are merely alternating thin layers of coal and coaly shale, practically worthless for industrial purposes. The district between the Irtych and Ichim Rivers, south and west from

[19] Aperçu des Explorations Géologiques et Minières le long du Trans-siberien," le Comité géologique de Russie, 1900, pp. 27–32, 52, 83–88.

Pavlodar on the Irtych, is marked by great irregularity in the seams; at Tyn-koudruk, one, 2 meters thick, thins away like a wedge, while another near by has coal charged with sand and thins away rapidly. Generally speaking, the seams are inconstant, at times swelling abruptly and at others disappearing. The variations do not appear due to the disturbance. The coal horizons, of which many were examined, occupy very limited areas. Some clean coal was seen, but there is little of it.

Eastward from the Ob River, one is beyond the Kirghiz Steppes. In the space between that river and the city of Atchinsk, the Lower Carboniferous is exposed frequently with, in general, the same features as farther west, except that some of molluscan forms found in the Ural region are wanting. The coal formation is triple and the seams are in the middle division, which consists of clays, shales and sandstones, with many remains of *Neuropteris* and *Cordaites* as well as *Anthracosia, Posidomya, Carbonicola* and other mollusks. The basin has an area of not far from 15,000 square kilometers and has many seams of coal but no attempt to develop them has been made.

An important basin is crossed by the railroad in the Jenessei region. Near Soudjenka, 130 kilometers from the city of Tomsk, this is 5 kilometers wide. It extends many miles northward, narrowing to disappearance; but it was followed for a much longer distance toward the south, with constantly increasing width. The dip is high, rarely as low as 10° and frequently as much as 60° to 90°. Nineteen seams of coal were seen, more than 0.75 meter thick, one of them 11 meters. The coal, mined somewhat extensively near Soudjenka, is much the same at all horizons; by some it would be classified with anthracite, while others would call it caking coal. Seams were seen at many localities on the Upper and Lower Angara River, north from Irkoutsk, everywhere characterized by irregularity of occurrence. The coal of this central region is much better than that of the Kirghiz Steppes, samples from Soudjenka and the Angara yielding only 3 to 6 per cent. of ash.

Cannel, 0.5 meter thick, was seen on the Ichim River, 60 miles north from the railroad.

Carboniferous deposits seem to be wanting in the region east from Lake Baikal.

Russia in Europe.

Murchison[20] believed the Carboniferous System of northern and central Russia to be equivalent to the Mountain Limestone and underlying deposits of Great Britain, while, on the western slope of the Urals, he recognized the Millstone Grit and Permian. In the Valdai Hills, Province of Novgorod, the Lower Carboniferous consists of, ascending,

Lower Limestone, with *Productus gigantea,* associated with sands and some coal beds; Moscow Limestone with *Spirifer mosquensis;* it has no coal in northern and central Russia, but there are seams in the southern Steppes; Upper Limestone, with *Fusulina cylindrica,* containing coal only in the southern Steppes.

The sands at base of the Lower Limestone have many pyritized plants, among them *Stigmaria ficoides;* bituminous shales associated with the sands contain coal. Those on the Pritchka River are 40 feet thick and contain 4 coal seams in the upper portion. The coal is extremely imperfect and is from 10 inches to 4 feet thick. Helmersen had described this as Moorkohle; it is impure, pyritous, slightly consolidated and is inferior to some Tertiary coals mined in portions of Germany. The cover is largely loose sands and variegated marls.

Nikitin[21] states that the lignite occurs in the Toula District near the Volga. The coal group, at same horizon as in the Valdai Hills, consists of alternating clays and sandstones with more or less considerable seams of coal. He thinks it strange that this material, in spite of its great age, has chemical and physical character so closely allied to that of lignite. Boghead, rich in oil, is present at several horizons. At one locality, several thin coals were seen at the base of the Lower Carboniferous, but they have insignificant lateral extent.

[20] R. I. Murchison, " Geology of Russia in Europe and the Ural Mountains," London, 1845, Vol. I., pp. 69–71, 78, 126.

[21] S. Nikitin, " De Moskau à Koursk," Guide des Excursions, XIV., St. Petersburg, 1897, pp. 4–7.

The Donetz coal basin in southern Russia was studied in 1892–94 by Tschernyschew and Loutougin,[22] who published a synopsis of their reports. The Basin occupies much of the provinces of Poltawa, Kharkow and Don Cossacks, and is drained by the Donetz River, emptying at northeastern corner of the Sea of Azov. The Carboniferous is exposed in an area of not far from 12,000 square miles, but borings through overlying deposits prove that the actual extent is much greater. The deposits are, as described by Murchison, in three divisions, but the highest one belongs to the Upper Carboniferous. The divisions are designated C_1, C_2, and C_3, in ascending order. The measurements by Tschernyschew and Loutougin are in great detail and the description notes the lithological character and fossil contents of each stratum. Condensed, the description is C_1, in its lower 4 subdivisions, consists of limestones and silicious marls, rich in marine fossils. Coal appears first in the 5th, composed of gray micaceous sandstone with subordinate beds of limestone, arkose and shale; the coals are thin. C_1 is characterized by *Productus giganteus*.

C_2 begins with a mass of sandstone, shale and limestone, in which *Productus giganteus* is wanting and *Spirifer mosquensis* is the notable form. Coal occurs in the second subdivision, but the seams rarely attain workable thickness. The third, shales, sandstones and insignificant limestones, has 9 coal seams from 0.35 to 0.75 meter thickness; though rarely reaching the maximum and varying greatly in thickness, several of these seams are mined extensively. At some localities they are excellent for coke, at others for gas, while at others they are anthracitic. Usually only one or two beds are "workable," but at Ouspenskoïé, there are 8. The fourth subdivision, 320 to 350 meters thick, almost wholly sandstone and shale, has 4 seams, rarely workable and often replaced with shale. The fifth, 250 meters thick and composed of sandstone and shale with about 6 meters of limestone, has 8 seams and is richer in coal than are the lower subdivisions, though the seams are very irregular. The extreme thicknesses in the important seams are 0.7 to 1 meter, but these in some cases thin away to insignificance. The sixth, 225

[22] T. Tschernyschew and L. Loutougin, "Le Bassin du Donetz," Guide des Excursions, XVI., 1897, pp. 4–10, 12–23, 27–29, 34, 50.

to 300 meters, is the most important coal-bearing portion. Of the 11 seams reported in the section, 8 have a maximum of 0.7 to 1.75 meter inclusive of partings. Marine fossils were observed in the roof of 5 seams.

C_3, about 2,000 meters thick, contains workable coal only in the lower horizons. The fauna changes gradually; forms of the middle division disappear and new forms appear, which are characteristic of the Upper Carboniferous in Timan and in North America. The lowest subdivision has 10 seams, but all are thin and the coal is poor. In one case, the roof contains marine fossils. Red to green shales are in the upper part of the section. The second is separated from the first subdivision by 11 meters of marine limestone and contains 2 or 3 coal seams, which are wholly unimportant. Arkose near the base has fragments of *Araucaria* and the section shows some green and red shale. The third subdivision has only thin streaks of coal and thin beds of red shale. The fauna and the flora are distinctly Upper Carboniferous.

The number of coal seams, which, at some place, attain workable thickness, is not more than 30; but the variability both in thickness and in quality is extreme; some disappear, others become thin and worthless while new ones appear. The coal loses volatile in the direction of increasing dip. At mines in the Almazny seam, along a northwest-southeast line, only 20 miles long, the volatile is 35, 30, 25, 18, 15 or less per cent. The proportion of volatile has no relation to nature of the roof or floor. The authors regard the Donetz coals as allochthonous, the convincing argument being the presence of marine fossils in the immediate roof of coal seams.

Permo-Carboniferous deposits are confined to the western side of the Donetz Basin, where they rest directly on the limestone closing-C_3. Deposition was continuous from Carboniferous to Permian and there is no evidence of unconformity anywhere. The deposits are regarded as Lower Permian and the abundant marine fossils are in greatest part forms characterizing the C_3, the Upper Carboniferous; the change in fauna is as gradual as that in passing from C_2 to C_3. The lower portion consists of clayey shales and gray, green or red limestones with some streaks of coal near the base. The upper portion consists mostly of red and green marls

with deposits of salt and gypsum. Some dolomites, regarded as equivalent to the Zechstein, were seen at one locality. These contain a Permian fauna. Disturbance followed the close of the Permian, and the overlying rocks are notably unconformable, occupying valleys in the eroded Paleozoic rocks.

Conditions in the southern Urals are much as in the Donetz Basin. Murchison[23] described them in his great work on Russia. At a later date he gave a synopsis of his conclusions, in which he states that the Permian deposits "occur in almost apparent conformity to the Carboniferous rocks." Coal appears to be wanting in Urals but the lower division contains streaks of impure coal in the central region between the Urals and the Volga River.

Spitzbergen.

Nathorst[24] has given in summary the results obtained by himself and others during exploration of the Spitzbergen region. The whole series from Lower Carboniferous to the Permian is present. The Lower Carboniferous, which is represented by the Kulm, rests unconformably on the Devonian. It consists, at base, of dark quartzitic sandstone, underlying yellow sandstone, on which rests a mass of bituminous clays and shale with fragments of ferns and, in the lower part, a thin seam of coal resting on a *Stigmaria* underclay, containing sphaerosiderite. Above this mass of shale and clay are sandstones, yellow and white, becoming red in the upper portion, showing coaly streaks at some places and at others lenses of coaly shale resting on *Stigmaria*-clay. The lens form is due to compression. The dip approaches 90°. The petrographic characters as well as the fossils indicate that the Kulm beds were deposited in shallow fresh-water. They suggest swamps at mouths of rivers.

The Kulm beds are followed by a mass of limestone, which, at base, shows transition to the Upper Carboniferous, and at top to the Permian. The system closes with rather loose marls and sandstones, holding less than 2 meters of limestone in the thickness of

[23] R. I. Murchison, " Siluria," 3d ed., London, 1859 p. 325 et seq.

[24] A. G. Nathorst, " Beiträge zur Geologie der Bären-Insel, Spitzbergens und des Konig-Karl--Landes," *Bull. Geol. Inst. Upsala,* Vol. X., 1910, pp. 321, 323, 325, 327, 330, 337, 347–350.

more than 30 meters. The total thickness of Carboniferous may be not far from 1,000 meters, as the maximum; but the several members vary greatly. Nathorst shows that throughout the whole section deep-water deposits are wanting. The Kulm, in greatest part, is of fresh-water origin; the limestones, beyond doubt, were laid down in shallow water during the long-continued slow subsidence of the area. The fossil wood is of a type indicating a sub-tropical climate. The deposits are conformable, the only irregularity being due to overlap.

Silesia.

The Upper Silesian Coal Field.—This extremely important field is between meridians 18° and 20° and is divided toward the southern border by the 50th parallel. In greatest part, it is within Prussian Silesia, but it extends eastwardly into Galicia and westwardly into Austrian Silesia. The area is almost 4,000 square miles, of which 2,400 are in Prussia. The great economic importance of this field has led to many careful and more or less detailed studies during the last eighty years. According to Dannenberg,[25] the deposits have been grouped into

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V. Saarbrück Stage   Sohrau beds ⎫
IV.                  Nikolai bed ⎬ Karwin or Orzesch beds
                     Ruda beds   ⎭
III. Sudetic Stage (Waldenburg)  Sattelflötz beds
II.                  Czenitzer beds ⎫
                     Loslauer beds  ⎬ Rybnik beds    Ostrau beds
                     Hultschun beds ⎭
   I. Lower Carboniferous    Golonog beds    Petrzkowitz beds
                     Kulm
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The Ottweiler stage is wanting and the presence of Permian is uncertain. The grouping is essentially that offered by Gaebler in 1898. Somewhat later, Michael[26] used other terms: Instead of Saarbrück he employs Mulden, as it occupies the central part of the field; Satterflötz is replaced with Sattel-group, while the Ostrau

[25] A. Dannenberg, " Geologie der Steinkohlenlager," Erster Teil, Berlin, 1908, pp. 170-172, 180-197.

[26] R. Michael, " Die Gliederung der oberschlesische Steinkohlenformation," *Jahr. k. k. preuss. Geol. Landesanst.* Band XXII., 1902, pp. 319-340.

beds are termed the Rand group because they are on the border of the field. The Rand or Ostrau beds form the Schlesische Stufe.

Dennenberg has given a careful synopsis of his observations and of those by other students in this region, which may be utilized here. The thickness of the Saarbrück and Sudetic stages is, at most, not far from 7,000 meters; but the coal is distributed unequally. The Sattelflötz, at most barely one-twenty-eighth of the whole mass, contains about one fifth of the workable coal. The deposits decrease toward the north and east, the Sudetic mountains being the source whence the sediments were derived. The Sattelflötz beds near Zabrze measure 240 to 250 meters but at the east, on the Galician border, they are only 14 to 15 meters. According to Gaebler, the Ostrau or sub-Sattelflötz beds are 4,000 meters thick near Ostrau at the southwest, but only 500 meters near Golonog on the extreme northeastern border of the field. The total of Upper Carboniferous diminishes from about 7,000 meters at the west to barely 1,220 at the east. This thinning of sediments leads to frequent disappearance of intervals with resulting union of coal seams and relative enriching in coal-content.

The Upper Carboniferous rocks in this field are remarkably uniform in general character; sandstones, mostly white, prevail; while shales are subordinate and become important only in the highest division. Clay ironstone is present in nodules or in workable beds. Conglomerates are insignificant and red beds are practically wanting. The maximum thickness of the several divisions is Saarbrück (Karwin or Orzesch), 2,700 meters; Satterflötz beds, 240 meters; Ostrau beds, 4,070 meters. The total of coal is 299 meters, of which only 169 are in workable seams.

But emphasis must be laid on the fact that this statement of coal resources is merely general and is the maximum. The number and thickness of coal seams vary from place to place; the Ostrau beds are usually barren in the northern parts of the field, but there are a few seams which occasionally become workable. The Satterflötz beds, "the glory of the field," show extreme variation. They are exposed by anticlines in the neighborhood of Zabrze, Konigshütte and Myslowitz, but elsewhere in the greater part of the Prussian area they are buried deeply. The chief expansion is at Zabrze on

the western side but thence, northward and eastward, the changes are as interesting as those in the Anthracite region of the United States. Five seams are mined at Zabrze; but just west from Beuthen, one finds that the thick parting between numbers 1 and 2 and the interval rocks between 4 and 5 have disappeared; at Königshütte, the 3d seam has become united to 4 and 5, so that now there are but the Upper seam, representing 1 and 2, and the Lower seam, representing 3, 4 and 5. But, at a short distance farther west, near Kattonitz, these two seams are so near together that they are mined as one. At the west, the coal of Sattelflötz beds is to the other rocks as one to nineteen, but at the eastern border it is thicker than the other rocks. Whether or not the newer seams overlap the older ones after union does not appear from the reports.

The same features are shown by the Saarbrück complex, which is present chiefly in the central portion of the field. Near Nikolai, Sohrau and Pless, it is 2,667 meters thick, with at least 253 coal seams, 45 being workable with about 75 meters of coal; but near Beuthen, 20 miles north, the Ruda beds, which near Nikolai are 589 meters thick with 49 meters of coal, are only 248 meters with 11.93 of coal; while in the Galician region the whole Saarbrück is but 1,014 meters with 35 seams and somewhat more than 60 meters of coal. The Ostrau-Karwin region is in Austria. The Ostrau beds occupy the Ostrau trough and most of the Peterswald. The Sattelflötz beds, as shown by Petrascheck and Mladek since the publication of Dannenberg's work, are present in the west side of Karwin trough, passing under the Saarbrück farther east. Marine deposits are characteristic of the Ostrau beds here as also in the northern areas. The number of coal seams is great and the quantity of coal makes the district important—in contrast with the other districts, where the Ostrau coals are almost unimportant.

Goeppert,[27] three-quarters of a century ago, studied the Silesian and Galician portions of this region. His investigations were made largely from the paleobotanist's standpoint, so that he had little interest in correlation and still less in economic studies.

Conglomerates are not wanting but the pebbles are rarely larger

[27] H. R. Goeppert, " Abhandlung eingesandte als Antwort auf die Preisfrage, etc.," Leiden, 1848, pp 107–206.

than a pea; the prevailing rock is sandstone, gray to yellow, which in some localities weathers to a carved or fretted surface. It is quartzose and has little cementing material. Clay shales are intercalated in the sandstone mass and they are associated with the coal seams. Near the coal, these 'shales often are rich in bitumen, becoming Brandschiefer and frequently containing much pyrite. Irregularity of deposit is evident from the rapid change of sandstone into clay shale. Sphaerosiderite occurs chiefly where the coal seams are thin and alternating with shaly clays.

This region is marked by the thickness, extent and regularity of the coal seams, according to Goeppert; but when he studied the area, the correlation was very uncertain. The thickness is from 3 to 12 feet, but at one locality it reaches 42 feet. About 20 seams are workable. Dips commonly are less than 12°, but near the Carpathians they are higher. The thicker seams are ordinarily in several benches, varying not only in thickness but also in character of the coal; some benches are caking, others, not. Laminated coal is the predominant type and occurs, as a rule, in the top and bottom portions; Grobkohle forms the best benches of thick seams and for the most part is confined to the middle, being found rarely in other parts; clean Pechkohle is less abundant and Blätterkohle seldom occurs. In great districts, every coal seam contains remains of plants, especially of *Sigillaria;* Faserkohle is in all seams and sometimes it predominates, making the coal loose.

At Zabrze, the seams [Sattelflötz] contain much Faserkohle; that material predominates in the highest, which is 13 feet thick. A sandstone quarry in the Brenz district, on the Poland border, has great stems of silicified wood—an unusual occurrence in the Upper Silesian field. Near Myslowitz he saw *Sagenaria* stems standing on the coal, one of them 4 feet high and 2 feet in diameter. In the Locomotive mine, there, erect *Sigillariæ* are abundant in the roof of the coal seams. On the Poland border, the lowest seam near Dabrowa is 78 feet thick, divided midway by 6 feet of Brandschiefer, consisting of compressed *Sigillaria* associated with a little clay. The same *Sigillaria* is in the coal along with Faserkohle. Goeppert states that the *Sigillaria* is incredibly abundant.

At Zawada in the Nikolai district [Saarbrück], the Friedrich

mine works two seams, 24 and 60 inches thick, separated by an interval of 48 to 54 feet. The lower yields a laminated, hard, coking coal but coal from the upper one was considered to be inferior. When the lower seam was almost exhausted, work was begun on the upper. Its coal resembles Blätterkohle, consisting of hard, glance-like lamellæ alternating with thinner dull laminæ, composed of compressed barks of *Lepidodendron, Calamites, Stigmaria* and *Sigillaria,* all distinct. Goeppert states that, in many ways, this resembles peat. At a mine in this Nikolai district, the coal contains great abundance of *Sigillaria* and *Lepidophloios* and an "incredible" mass of *Sigillaria* is in the roof. There he obtained *Sigillaria* and *Alethopteris* with leaves only slightly brown and completely flexible, preserving the minutest details of structure. Union of coal seams is a familiar feature in the Nikolai district. Additional observations by this author will find place in another connection.

Goeppert makes only passing reference to the Austrian part of the field; but material information respecting one portion has been given by Petrascheck[28] in a paper dealing especially with the Peterswald trough, lying between the Ostrau trough at the west and the Karwin trough at the east. With Stur and Gaebler, he recognizes Ostrau beds in the western part of the trough but he finds the Sattelflötz beds in the eastern portion, where the disturbance was so severe as to cause inversion. A serious difficulty encountered in correlation was found in the sudden changes in character as well as thickness of the deposits, which mark some horizons more than others. It appeared to him that the Ostrau beds were deposited on a rudely level oscillating coast, so that paralic and limnic conditions alternate. In discussing the evidence of overturned stratification, he presents some facts which have interest here.

The layer of "Schramm," soft, more or less clean coal, passing at times into shale, is, as a rule, on the floor of the coal seams; occasionally, it is found in the body but very rarely on top of the coal. In the Sophien coal mine, all coal seams have the "Schramm" on top, the Faux-mur having become the Faux-toit. Reed-beds or underclays with *Stigmaria* appendages crossing the bedding, are the

[28] W. Petrascheck, "Das Alter der Flöze in der Peterswalder Mulde, etc." *Jahrb. k. k. geol. Reichsanst.,* Band 60, 1910, pp. 779–814.

roof, not the floor of the seams in their present position. In one seam, upright stems stand on the coal, in the present floor, but original roof. The note on Cannel is worth citing, as it indicates unusual conditions in the area. There one finds in the upper seams of the Ostrau as well as in the Karwin seams, lenses of cannel or of dense cannel-like Brandschiefer, "Sklok" of the miners. Petrascheck states that, as a rule, this is the top of coal seams; he knows of only one instance where it is at the bottom. This he regards as the ordinary condition in coal regions, thus taking issue with Potonié, who maintains that it occurs usualy at the bottom of seams. But in the American coal areas, cannel is found in any part of coal seams, just as the analogous material is found in peat deposits.

The Sattelflötz area, farther east, is thick, consisting mostly of sandstone and arkose with intercalated beds of red sandstone. The important coal seams have been correlated definitively with the main seams of the same group in upper Silesia. The evidence was obtained in three borings. Marine forms are present at 20 feet below the Prokop (Pochhammer) seam and they mark the top of the Ostrau. At Justin, the coals have local cannel in Hangend. Splendid, widespreading, branching *Stigmaria* are in the floor of the Ivan seam, associated with sphaerosiderite. Seam II. has cannel-like coal near the top, covered with black coal, underlying a shale with marine mollusks. Erect *Sigillaria* were seen in the roof of the Hermann seam.

At the Albrecht shaft, the Eugen seam has many prostrate as well as erect stems in the roof and indistinct *Stigmaria* are in the floor. Stur found pebbles in this coal. Long ago, Bartonic collected from a dark shale in this seam a marine fauna, *Nucula, Pleurotomaria,* and *Orthoceras* as well as *Anthracomya*. The Koks seam contains plant-bearing concretions of iron stone and a layer of shale with similar concretions rests directly on the coal; it too has a marine fauna. A sandstone near the Koks seam has so great number of stems of *Lepidodendron* and *Sigillaria* that Petrascheck regarded it as a strand formation. Pebbles were seen in the younger Ostrau coals. They are numerous in the Josefi coal, granite, porphyry and quartz; they are present also in the Kronprinz seams but are smaller than in the other. Erect stems occur in the

roof of the Juni seams. Cannel-shale and sphærosiderite are characteristic and several marine horizons were observed.

Petrascheck[29] has called attention to the occurrence of coal pebbles in a sandstone at Brzescze in the Galician area. This sandstone, containing many fragments of *Sigillaria,* is shown in the Andreas shaft and belongs to the Upper Schatzlar [Saarbrück]. This sandstone for the most part is moderately coarse, but, where the pebbles of coal occur, the grain is coarser, almost conglomerate. Many of the coal fragments are well rounded, others have rounded angles while in others the edges are still sharp. Along with these are streaks of coal, insignificant in extent, and fragments of shale were seen. The lamination of the coal pebbles does not coincide with that of the sandstone. The largest pebble seen measured 6 by 5 by 3 centimeters.

The fragments include glance and laminated coal as well as cannel and show the peculiarities of each type; glance fragments are sharply angular but those of cannel and laminated coal are more or less rounded. Petrascheck is convinced by the form and structure that these were not balls of peat or pieces of wood, when entombed. For him, the evidence indicates clearly that the several types of coal seen in the pebbles had attained their characteristic features in Carboniferous time. The fragments are unquestionably of Carboniferous age for no older coal-bearing series exists anywhere in the surrounding region; but the source has not been discovered.

The Lower Silesian-Bohemian Basin.—One reaches this basin at about 150 miles north of west from the Upper Silesian field. The area is not far from 750 square miles; originally it was open toward the southeast, but was closed at the north and west by the Riesengebirge and at the east by the Eulengebirge. The northwestern and eastern portions are in Silesia but the southwestern, including much of the interior basin, is in Bohemia. The region was studied in great detail by Goeppert and recently Dannenberg[30] has summarized

[29] W. Petrascheck, " Das Vorkommen von Steinkohlengeröllen in einem Karbonsandstein Galiziens," *Verh. k. k. Geol. Reichsan,* 1910, pp. 380–386.

[30] H. R. Goeppert, " Abhandlung, etc.," 1848, pp. 207–275; A. Dannenberg, " Geologie der Steinkohlenlager," 1908, pp. 147–184.

the results of his own investigations with those of other observers. According to Dannenberg, the Lower Carboniferous of the Kulm stage is present in the Waldenburg district on the northern and eastern sides; it consists chiefly of coarse material but sandstone and shale are in the upper part, with occasional limestone. The colors are gray, brown and red. Organic remains are rare and the few animal remains belong to marine types.

The Upper Carboniferous, resting unconformably on the Kulm, is a monotonous accumulation of conglomerates and sandstones; these are usually almost white, but locally in rather wide spaces these beds, owing to infiltration of iron salts, are red and very similar to Rothliegende. The proportion of shale is remarkably small and it is found almost wholly in association with seams of coal. The divisions are

Radowenz beds	Upper Ottweiler
Schwadowitz beds	Lower Ottweiler
Schatzlar beds	Saarbrück
Waldenburg beds	Sudetic

Marine fossils are absent and the only animal remains belong to fish, phyllades and ostracoids, which may be either fresh-water or brackish water-forms. The Rothliegende boundary cannot be determined; Coal Measures pass upward gradually and, in the southwest wing of the basin, the similarity of the rocks is so great that Upper Carboniferous was mistaken by some observers for Rothliegende. Local discordance has been discovered here and there in the Upper Carboniferous, there being local gaps in the succession; similar discordance between Upper Carboniferous and the Rothliegende has been observed, but evidence of general discordance between Upper Carboniferous and Permian remains to be discovered.

Groups of workable coals are in all the stages, but they are separated by thick deposits of barren rock. The irregular deposition of the several stages and the notable variations in thickness of coals lessen greatly the importance of this field. No coal seam is persistent throughout the exposed area of its stage; each decreases in all directions from a maximum and not a few seams disappear. No definite relation exists between depth from surface and the

character of the coal; maigre and caking coals alternate, but in a general way there is more of fat coal in the higher than in the lower divisions. Formation of coal began during the Kulm, which, on the northern and northwestern border, contains streaks of anthracite, up to 10 inches thick, associated with coaly shale. But accumulation was unimportant prior to the Sudetic stage.

The Waldenburg (Sudetic) beds are the Liegendzug at Waldenburg; workable seams in the eastern part of this district are few, thin, dirty and varying much in thickness. Just beyond Altwasser, 16 seams were seen, of which 6 to 13 are workable in the several mines. Farther toward the south, only one seam is workable—and locally—near Tannhauser, the whole stage thins away. The seams are 10 to 50 inches thick.

The Schatzlar (Saarbrück) stage is the Hangendzug at Waldenburg and is separated by a thick practically barren interval from the Liegendzug. The rocks in this interval are conglomerates at base, passing upward into coarse sandstone with some shale and thin streaks of coal. These are overlain by the Hochwald porphyry, which is 834 meters thick west from Waldenburg. The rocks below the porphyry are the Weisstein beds of Dathe.[31] The Schatzlar stage is important chiefly near Schatzlar in the western part of the field within Bohemia. Northeastward from that locality to Landeshut the coals are insignificant; but toward the southwest workable seams are at Gottesburg. Along the northern outcrop in Prussia, the stage is unproductive, but at Waldenburg the seams are numerous once more and 12 to 15 out of the 40 shown in the section are workable with maximum thickness of 2 to 4 meters. But here as elsewhere workable thickness never occurs in any considerable space and important localities are practically isolated.

The Schwadowitz and Radowenz, representing the Ottweiler, are exposed in the southwestern part of the field, where the coal seams are of merely local importance. The succession, descending, is:

Radowenz, enclosing 5 to 7 seams, of which 2 are workable locally;

[31] E. Dathe, "Der Verbreitung der Waldenburger und Weisssteiner Schichten in den Waldenburgen Bucht," *Verh. d. d. Geol. Gesellsch.,* 1902, pp. 189–193.

Barren interval, "Hexenstein Arkose," alternations of arkose, con-
glomerates, sandstones, and clay shale, with stems of *Arauca-
rites schrollianus* (beds of the petrified forest) ;
Schwadowitz beds with 3 to 5 seams, 2 of them workable locally.

The prevailing color of the Ottweiler is red, but in the clay shales
it is gray.

Goeppert[32] described the remarkable accumulation of petrified
stems in the Hexenstein arkose. This is exposed on a high sandy
ridge, extending northwestwardly from Radowenz to beyond
Schatzlar. The fragments, weathered out from the soft sand-
stone, are extremely abundant in an area of not far from 20 English
square miles. All of the stems seem to be prostrate and lie in
practical conformity to the bedding of the sandstone; but they show
no evidence of transportation such as should be expected if they had
been washed out from their place of growth. The conditions led
him to believe that the fragments are the remains of an overthrown
forest. Those lying exposed on the surface have diameter of 1 to
4 feet, with a round or oval section and they are not waterworn; the
length is from 1 to 6 feet, though in some cases it is 14 to 16 feet.
The stems belong to *Araucarites schrollianus* and *A. brandlingii*.
Petrified stems are numerous near Schatzlar as well as at some other
localities, but the great accumulation is at Radowenz.

In his earlier work on the eastern side of the field, Goeppert
divided the area into two districts, Waldenburg at the north and
Neurode at the south; but these are continuous. The dips are high,
usually between 45° and 70° and the whole region was disturbed
greatly by porphyry outbursts. Conglomerate, almost wholly want-
ing in the Upper Silesian Field, and coarse sandstone prevail; but
these coarse rocks are not in contact with coal seams. The number
of seams is greater than in the other Silesian field, but "rest pe-
riods," during which shales and coal accumulated, were brief and
irregular; so that, while the maximum thickness of coal is great, the
available quantity is comparatively small. In Upper Silesia, the
coal seams consist chiefly of tree-like *Lepidodendron*, some *Sigil-*

[32] H. R. Goeppert, "Ueber den Versteinden Wald von Radowenz bei
Adersbach in Böhmen, etc.," *Jahrb. k. k. Geol. Reichsan.*, Band VIII., 1857,
pp. 725–738.

laria, a smaller number of *Calamites* and still fewer ferns; but in the field of Lower Silesia, though tree-like *Lepidodendron* and *Sigillaria* are not wanting, the prevailing forms are *Stigmaria, Equisetum* and ferns. Cannel-like coal occurs in the lowest seam.

From the Silesian-Bohemian line to beyond Altwasser, the Carboniferous rests on Transition rocks, but beyond Altwasser, usually on gneiss and mica schist of the Eulengebirge. In this, the Waldenburg district, the Hangend is red sandstone with occasional layers of limestone, containing fish remains but no plants; coal appears to be wanting but a black bituminous shale, 24 to 30 feet thick, is plant-bearing.

The lower coal group (Waldenburg) has many coal seams with a maximum thickness of about 43 feet, but the variations are great. A seam near Albendorf, 22 inches, splits into layers an inch to a half inch thick, of which the surfaces are covered with *Stigmaria ficoides.* Mineral charcoal is not abundant in this coal; the sandstone contain much petrified wood. Another seam, near Forste, yields a hard bituminous coal but the numerous clay parting make the seam almost unworkable; the coal contains *Stigmaria, Sigillaria, Sagenaria* and *Calamites.* The roof shale usually has a varied assemblage of plants, but at one locality *Calamites* is predominant. Goeppert saw, in the sandy roof of the highest seam, 4 vertical stems of *Sagenaria,* without roots, standing on the coal. In their interiors he found remains of *Calamites.*

Near Altwasser this group has 37 coal seams, but near Wäldchen there are only 2. Near Ober-Altwasser, 15 seams were seen, of which 6 can be worked, being 20 to 30 inches thick; but the dip is high, 60 to 70 degrees. Ordinarily, the coal in this neighborhood is laminated and, when split, the surfaces show *Stigmaria ficoides* as well as *Sigillaria, Sagenaria* and *Calamites.* The roof of seams 2 and 10 is, in each case, a mass of *Alethopteris* fronds, closely packed and associated with a very little clay. This condition was found persistent for 4,800 feet in one mine on seam 2. *Stigmaria* abounds throughout this lower group, not only in the clays, but also in the coal itself. Goeppert emphasizes many times the difference in species observed in superimposed coal seams as well as in the

same seam at different localities. Evidently there was localization of contemporaneous floras.

The upper coal group, above the Hochwald porphyry, has 80 seams of coal, 2 inches to 6 feet thick, but only 3 or 4 are workable, as partings are numerous. There are two subgroups, separated by a barren interval.

In the lower subgroup, he found resin by no means rare in seam 1; seams 4, 5 and 11 are caking; seam 6 has Sandkohle and seam 9 consists of Sinterkohle. Four has many thin layers of mineral charcoal; 11 is divided in distinct benches by partings of that material; but 5 has very little of it. The mineral charcoal is derived from *Araucarites* wood. *Stigmaria* is present in the coal at one mine; the upper bench of another seam contains *Sigillaria, Sagenaria* and *Stigmaria*. The southward prolongation of one seam has an abundant flora, which differs materially from that found in the northern prolongation.

The upper subgroup has 19 coal seams and the dip is 18° to 20°. The coal contains *Sigillaria, Sagenaria, Lepidophloios* and much mineral charcoal, the last in fragments up to 6 inches long. Resin is in the coal of a mine near Waldenburg. Erect stems of *Sagenaria* are in the roof of seam 9 and petrified wood was seen in a sandstone quarry. At the Sophien mines, the coal shows *Stigmaria* and *Sagenaria* on the surfaces of splitting; in the same neighborhood, another seam rests on clay, crowded with *Stigmaria* and its roof holds an abundant and varied flora. At the Fund mine in Charlottenbrunnen, the roof of a seam is a compact, fine-grained sandstone, in which he saw great prostrate stems of *Lepidodendron* and *Sigillaria*, 40 feet long and 30 inches in diameter. The floor has abundant *Stigmaria* and occasional *Calamites*. Many *Stigmaria* with some *Lepidodendron, Calamites* and *Noeggerathia* were seen in coal at the Segen-Gottes mine. The flora of this sub-group is most abundant, where the coal is thickest, but many types are confined to very restricted areas.

Similar conditions prevail in the Neurode district, where the higher deposits are reached. Near Buchau he saw in sandstone, several clumps of *Araucarites* stems, all apparently prostrate. Near

Ebersdorf, erect stems, probably *Sagenaria,* stand on the coal. At Mölka, he obtained *Unio carbonarius* from a clay containing ferns and lycopods.

Hungary.

The coals of Hungary,[33] confined to the Banat region, belong to the highest part of the Upper Carboniferous and to the Rothliegende. They are unimportant and are present in four isolated districts, Eibenthal-Ujbánia at the east, Lupak-Gerlistye, Resicza-Szekul and Zagradia at the west. The deposits in the Ujbánia district are exposed in an area of not more than 800 by 1,700 meters and rest on gneiss and serpentine. Hantken's section, ascending, is

(1) Fine-grained sandstone, micaceous, with many ill-preserved plants, no ferns, but *Stigmaria ficoides* and *Calamites cystii,* 10 to 15 meters; (2) Donau coal seam, 1.5 to 14 meters; (3) porphyry, the immediate roof of the Donau and floor of the next seam, 30 to 50 meters; (4) Wenzel coal seam, 20 to 40 meters; (5) iron ore and porcelain jasper, underlying the Rothliegende conglomerate.

The Donau coal seam varies abruptly and frequently passes into a bituminous clay shale, known as "Brand"; when thick it is divided by 16 to 50 inches parting and laminæ of clay are so numerous in the coal as to make the product inferior; but selected coal is good, showing: water, 2.17; volatile matter, 14.64; fixed carbon, 79.75; ash, 3.62; and sulphur rarely exceeds 1 per cent. The coal is tender and the loss in mining is 50 per cent. The section at the Donau mine is: (1) Clean coal, 0.32; (2) parting, 0.20; (3) less clean coal, 1 meter; (4) coaly shale, "Brand" 20 meters. This seam disappears toward the west.

The Wenzel seam yields harder coal than that from the Donau, but it varies much in thickness and quality; only the upper portion is mined. The variation in thickness in both seams is so abrupt that systematic mining is impossible and the coal is taken out wherever it seems to be good.

No workable seam has been found in the Upper Carboniferous of the Lupak-Gerlistye district but the Rothliegende, consisting of

[33] M. Hantken, "Die Kohlenflötze, etc., der Ungarische Krone," 1878, pp. 24-44.

sandstones and clay shales, has some seams which occasionally attain workable thickness. Coal seems to be confined to the lower portion which is made up of mostly dark clay shale; the middle division is chiefly red sandstone but contains some dark shale, yielding plants; the upper division, red sandstone and micaceous shale, contains *Walchia, Taeniopteris, Pterophyllum, Callipteris* and other genera. The Zagradia district has no available coal.

The Szekul Valley is west from Resicza. The Coal Measures are exposed in a small area, where they rest on gneiss and underlie the Rothliegende. The boundary between Upper Carboniferous and Rothliegende cannot be determined as the passage from one to the other is exceedingly gradual, lithologically, and there is no unconformity. Four seams of coal are in the Coal Measures with maximum thickness of 0.75, 2, 1.50 and 1.30 meter, but the variations in thickness are so abrupt that, in each case, the coal is available in very limited spaces. The dip is not far from 45°, but changes in thickness are due in small degree to the disturbance. Partings are numerous; those of the third seam are blackband, which at times replaces the coal—in one mine this condition continued for 200 meters. The coal is very tender, barely 10 per cent. of lump coal being obtained. It yields a remarkably good coke; the ash is from 7 to 16 per cent., but washing removes about half of it. It is no longer necessary to resort to washing, as mixing the dust coal of Szekul with that from the Liassic coal of Doman gives a coke without excessive ash.

Bohemia.

Coal has been found in a number of more or less widely separated areas within western Bohemia as well as in one within the southern portion. The general succession throughout is so nearly the same, that many students in later days conceive that the western areas are merely fragments of a once continuous field, intimately related to the Saxony basins at the north, and that there may have been a connection with the Silesian areas at the east. As Dannenberg has said, they are all limnic, as appears from the irregularity of the deposits, including the coal seams, which thicken and thin, often wedge out and abruptly change in character; the coal seams,

few in number, vary greatly; the deposits were laid down in deep troughs on Cambrian and Pre-Cambrian rocks and decrease toward the middle line of the trough. The unevenness of the surface explains absence of lower members at some localities. The succession is Coal Measures and Rothliegende and the passage from one to the other is so gradual that no boundary can be determined; the relation of Upper Carboniferous to Permian was in dispute for a long time and, even now, the matter seems to be undetermined at several localities. Katzer and others of the older workers divided the deposits into the Radnitz beds at the base, belonging to the Coal Measures, followed by a Middle Zone, with the Nürschan coal seam, and on top, the Kounovaer beds; the last two were thought to be Permian. Borings made in areas where exposures are rare, led v. Purkyne[34] to a different conclusion. The succession in a boring made where the Pilsen Basin is deepest and where exposures are rare, is, descending: (1) Upper red clay shales, red and variegated shale and sandstone, 155 meters; (2) upper gray clay shales, with gray to white sandstone and coal seams, 180 meters; (3) lower red clay shales, red and variegated shale and marly shale with arkose, 52 meters; (4) lower gray shale, gray shale and gray to white arkose, with at least 9 coal seams, 419 meters. He thinks that earlier students had failed to recognize the existence of two red deposits, for no borings had been made and exposures are very rare. The Lubna coal seam and the Nýran cannel are at the same horizon. Each of the coal-bearing divisions, composed of gray to black shale and gray to white sandstone, underlies a division of red shales and sandstones, barren of coal.

Weitkofer,[35] in a review of the northern basins, grouped the Permo-Carboniferous deposits into: (d) Upper red clay shale, Lihnaer beds; (c) dark gray clay shales, Schlaner beds, containing the Pilsen and Schlan coal seams; (b) lower red clay shales, Teinitzler beds, 190 meters, with no fossils aside from stems of *Araucarites;* (a) gray sandstone group, Kladno-Pilsener beds, 300 to 400 meters,

[34] C. R. v. Purkyné, "Zur Kenntnisse der geologische Verhältnisse der mittelböhmischen Steinkohlenbecken," *Verh. k. k. geol. Reichsan,* Jahrg. 1902, pp. 122–125.

[35] K. A. Weitkofer, "Geologische Skizze das Kladno-Rakonitzer Kohlenbecken," the same, pp. 399–420.

with the Kladno Hauptflötz at base.   The Lubna and the Nürschan coals belong to the coal group in lowest part of the gray sandstone.

Dannenberg[36] states that the Lower Carboniferous and the Waldenburg (Sudetic or Schlesische stage) are wanting and that the series begins with the Saarbrück, to which he refers the Kladno-Pilsen sandstones as equivalent to the Schatzlar beds of Silesia; but the upper part of those beds are now regarded as belonging at the base of the Ottweiler and as equivalent to the Schwadowitz beds.

The Teinitzler beds (Hexenstein of Silesia) and the Schlaner (Radowenz) represent the Ottweiler, and the Lihnauer are regarded as undoubtedly Rothliegende.   The Saarbrück consists chiefly of thick sandstones and conglomerates; the Ottweiler is mainly red shales and sandstones, but it has much gray shale and white sandstone.   The Rothliegende (Lihnauer) has its characteristic flora. Deposition apparently was continuous throughout and at some localities the higher beds distinctly overlap the lower.   The Lubna-Nürschan coal seam is proved to belong to the basal coal group not only by stratigraphical relations but also by the associated flora, which is Carboniferous.

The several basins from north to south are the Kladno-Schlan-Rakonitz, which is west from Prag and north from the Bersum River; the Pilsen and farther south the small areas of Radnitz, Miroschan and Merklin.

The Kladno-Rakonitz basin, extending southwestwardly from Kralup to beyond Rakonitz, has a gross area of not far from 450 square miles (1,100 to 1,200 square kilometers), but the productive area is very much less.   The stratigraphy is simple as it is not obscured by disturbance, the dip rarely exceeding 6°, except on the extreme border, where it becomes at times 15° or 20°.   The largest coal seam, known as Grundflötz or deep Radnitz, is at the base, often separated by only a thin deposit from the older rocks.   Locally it becomes 6 meters thick, but ordinarily it is so dirty as to be worthless.

The Hauptflötz or Upper Radnitz seam, 3 to 18 meters above the Grundflötz, has been traced for 60 meters along the strike and has been followed for 4 kilometers along the dip.   It is extremely

[36] A. Dannenberg, "Geologie der Steinkohlenlager," pp. 232–257.

irregular. At both extremities of the basin it is too thin to be worked, but in two sub-districts, near Kladno at the north and Rakonitz at the southwest, it becomes workable; but even in these the variability is serious; a strip without available coal divides the Kladno district. In that district, the Hauptflötz at times rests directly on the older rocks, the Grundflötz being absent. It is in three benches with 3.75 to 5 meters of partings. In the eastern part of the district, the middle and lower benches are practically worthless, the ash being 26 to 28 per cent.; in the western portion the seam, 12 to 18 meters above the thick but worthless Grundflötz, is still triple, but the partings have become thin, so the whole mass, 9 to 12 meters thick, is mined as a single bed. In the Rakonitz area, the Hauptflötz occasionally has 4 to 5 meters of coal, but, especially toward the west, it tends to break up, so that there are few localities where it can be mined. Coal in the northern part of this basin is maigre and dirty, but near Kladno, it becomes fatter and at times less dirty: ash varies from 1 to 30 per cent.; caking coal is rare and cannel occurs at some localities.

Near Lubna, beyond Rakonitz, is the Lubna seam, of which Katzer[37] has given the section, which, descending, is: (1) Compact coal, in part brown, 0.30 to 1.10; (2) black clay parting, 0.03 to 0.20; (3) black cubical coal, 0.20 to 0.30; (4) compact brownish cannel with *Stigmaria*, 0.20 to 0.25; (5) thinly laminated Brandschiefer, with remains of ferns, 0.10 to 0.20; (6) clay with sphærosiderite, 0.20 to 0.50; (7) hard Brandschiefer, with remains of plants, 0.10 to 0.20.

The accepted reference of this seam, at the time when Katzer's work was published, was to the Permian, but later studies have proved that its place is in the basal portion of the Saarbrück and that the associated flora is Carboniferous, not Rothliegende. The presence of abundant *Stigmaria* in the cannel is worth noting. The same form abounds in a clay parting near Rakonitz.

The higher coal group, in upper part of the Schlaner beds, is separated from the lower group by the great mass of the Kladno-Pilsen sandstones, the Teinitzler beds and the lower portion of the

[37] F. Katzer, "Geologie von Böhmen." 2te Aufl., Prag, 1902, pp. 1118, 1158.

Schlaner beds, not less than 600 meters of rock. It is but a short distance below the Lihnaer red beds, belonging to the Rothliegende or lower Permian. Dannenberg calls this upper group " modest "; usually there are two coal seams, the upper, 0.5 to 1.04 meter and the lower, 0.3 to 0.4 meter thick, parting included in each case. Near Schlan, these seams are separated by an interval of 8 meters but, toward the west, they approach and finally become one seam, 0.4 to 1.7 meter thick. The coal is rich in volatile and contains about 14 per cent. of ash. The floor is a bed of sphærosiderite, with finely preserved plant remains. The roof is a Brandschiefer, termed " Schwarte," which approaches gas coal in composition but has no practical value. It has yielded a rich harvest of crustaceans, fish and *Stegocephalus.*

Lipold,[38] who believed that the Schlaner beds are Permian, has given the section of this bed as exposed near Schlan; it is:

(1) " Schwarte," 8 inches; (2) coal, 1 foot 8 inches; (3) clay, 3 inches; (4) coal, 1 foot 8 inches; (5) clay, not measured. This " Schwarte " is tender, black-brown Brandschiefer, so rich in bitumen that it ignites readily. Lipold asserts that it distinguishes Permian coal from that of the Coal Measures.

There are comparatively few exposures in the middle of the basin; borings, reported by Katzer,[39] show that the upper coal group is present on the western side. The borings begin in Rothliegende; the first reached biotite granite at 74.5 meters, that being the country rock. A coal seam, 0.49 meter, was pierced at 71.8 meters. In another boring, a seam of " Schwarte " and coal, 1.06 meter, was pierced at 89.59 meters from the surface, and was identified with that of the first boring. It underlies a clay shale and rests on dark clay shale, containing streaks of coal. An argillaceous sandstone at 17 meters from the surface contains fragments of *Araucarites* and appears to be in the undoubted Rothliegende. The boring ended at 23 meters below the coal seam, but did not reach the gran-

[38] M. V. Lipold, " Das Steinkohlengebiet in nordwestlichen Theile der Prager Kreises in Böhmen," *jahrb. k. k. geol. Reichsan.,* Band XII., 1861-2, pp. 507-509.

[39] F. Katzer, " Zur Kenntniss der Permschichten der Rakonitzer Steinkohlenablagerung," *Verh. k. k. geol. Reichsan.,* Jahrg., 1904, pp. 291-293.

ite; evidently the old surface was irregular and the overlap is notable, for only the highest part of the Schlaner beds is present.

The Pilsen Basin, not more than 30 miles south from Rakonitz and at extreme western extremity of the larger area has a total extent of not far from 150 square miles; the succession is practically the same as in the basin at the north, but the strata have endured much greater disturbance. Dips on the border reach 55°, though in the interior they sometimes become insignificant. The lower or Radnitz group shows 3 coal seams, known locally as the Fürstenflötz, Oberflötz and Unterflötz, the second and third being equivalent to the Hauptflötz and Grundflötz of the Kladno-Rakonitz region, while the highest seam is the same with that at Lubna near Rakonitz.

The variations in interval-thicknesses within this petty area are as remarkable as those proved by actual mining within the Anthracite fields on Pennsylvania. Dannenberg gives these measurements for opposite sides of the basin, separated by not more than 10 or 12 miles:

	Eastern Side.	Western Side.
1. Upper coal group.		
2. Interval 200		
3. Fürstenflötz......................0.32 to worthless		0.5 to 1.15
4. Interval ....15 to 132		17
5. Oberflötz ....1.1 to 2.1		1.0 to 2.0
6. Interval ....45 to 70		18
7. Unterflötz ....1.8 to 4.4		0.5 to 1.0

The surface of the underlying rock is uneven, so that the Unterflötz is often wanting. The important seam is the Hauptflötz, which is usually 1 to 2 meters thick, but toward the north, occasionally swells to 3 or even 5 meters. The highest or Fürstenflötz is available midways in the basin, where it is known as the Nürschan cannel. Katzer[40] placed this in his "Middle Zone" and believed it to be lower Permian. He has given a detailed section of the bed as seen at Nürschan: (1) cubical black coal, 0.30; (2) black clay, 0.03 to 0.30; (3) cubical black coal, 0.30; (4) cannel, rich in *Stigmaria,* a few ferns, some bones; (5) Brandschiefer, thinly laminated, remains of ferns, some saurians and fishes, 0.25; (6) Platterkohle, in thick slabs, the chief source of saurian remains, with streaks of clay,

[40] F. Katzer, "Geologie von Böhmen," p. 1148.

0.30; (7) blattering [coarse] coal containing *Calamites*, replaced with pyrite, 0.08.

This section certainly bears close resemblance to that of the Lubna seam. The "gas coal" is usually shaly in structure but it passes into true cannel. It is clearly a lens as the thickness varies from a few centimeters to more than a meter. The Brandschiefer contains the remarkable Nürschaner fauna described by Fritsch and thought by him to be Permian, though its species differ from those of the higher deposit. The flora above it would seem to indicate an earlier age as it is very closely related to the Upper Carboniferous. According to Dannenberg, coal like that of Nürschan occurs occasionally, but locally, in the Unterflötz. The upper coal group, in the Schlaner beds, is unimportant; it contains two coal seams, but these are "workable" in only limited areas.

The Radnitz Basin, west from that of Pilsen, is very small and preserves only the Kladno-Pilsner beds which have an average thickness of about 100 meters; the succession is Barren sandstone, at most, 30 meters; shale with two coal seams, 40 to 45 meters; sandstone and conglomerate, very thin at times but occasionally reaching 60 meters. The Unterflötz is about 4 meters thick, but partings make the coal dirty; the few good layers are replaced with rock toward the middle of the basin. The Hauptflötz is 10 to 11 meters thick in the southern part of the basin. It is triple, but the middle bench alone is persistent; the lower is often replaced with rock and the upper thins away toward the northeast.

A petty area of anthracite coal is present near Budweis in southern Bohemia; it was studied by Katzer[41] soon after resumption of mining operations in 1890 and his results were published several years later. The exposed area of the deposits, believed by Katzer to be Permian, is barely 6 square miles. At the east and west the underlying rocks are Archean; at the north and the southwest, Tertiary beds overlie the Permian. There are two divisions; the lower consists essentially of conglomerate, sandstone and arkose; the upper has at base the coal group on which rest prevailingly red beds.

[41] F. Katzer, "Die Anthracit führende Permablagerung bei Budweis in Böhmen," *Oesterr. Zeitsch. f. Berg- und Hutt.*, Jahrg XLIII., 1895, sep. pp. 1–26.

The upper deposits show none of the regularity characterizing those of the lower division. The coal group consists of dark gray to almost black shale and sandstone, with thickness of not more than 20 meters. The seam of anthracite is from 80 to 120 centimeters thick; the dip at the important mine is toward north-northwest at abut 30° and there is little variation in thickness. The coal is clean anthracite throughout, except locally, where a thin black parting with some pyrite is found. The volatile varies from 6.2 to 6.8 per cent. and the ash from 6.4 to 9.4; complete analysis gives carbon, 88.90; hydrogen, 2.91; oxygen and nitrogen, 2.10; sulphur, 1.49; water, 1.80; ash, 2.80.

Dips vary from 1 to 45° and the whole district is much broken by faulting.

Germany.

Saxony.—The coal basins of Saxony, in the southern part of the kingdom are small, but the seams are often thick, yield good coal and are of great economic importance. The Zwickau and Lugau areas, known as the Erzgebirge basins, are at the southwest and the Döhlen (Plauenschen Grundes) is at a few miles away toward the norheast. Coal has been mined in some localities for centuries and the region has been studied by many geologists.[42]

The petty basins of Hainichen and Ebersdorf on northeastern border of the Carboniferous region hold deposits of Culm age. The lower division or Grundconglomerate has maximum thickness of 2,000 feet, but this decreases rapidly toward the south until the whole Culm is barely 1,700 feet, of which not more than one half belongs to the lower division. The coal-bearing or upper division, consisting mostly of sandstone, has four thin seams, which have been

[42] The works examined are H. B. Geinitz, " Die Steinkohlen Deutschlands und anderer Länder Europa's," Band I., 1865, pp. 45–90; H. Mietzsch, " Geologie der Kohlenlager," 1875, pp. 150–156; " Erlauterungen, etc., Blatt III., 1877; Th. Siegert, " Erlauterungen, etc., Th. Siegert, " Erlauterungen, etc., Das Steinkohlen-revier in Lugau-Oelsnitz," 1882; J. T. Sterzel, " Erlauterungen, etc., Section Stellberg-Lugau, Blatt 113 "; " Palaeontologische Character des Steinkohlenformation und das Rothliegende von Zwickau," 2te Aufl., 1901; R. Hausse, " Steinkohlenbecken der Plauenschen Grundes (Döhlener Becken)," 1892; A. Dannenberg, " Geologie der Steinkohlenlager," Band I., 1908, pp. 199–224.

mined for local use. The coal is low in volatile and is said to be an excellent fuel.

The Coal Measures occupy depressions in gneiss, crystalline schists or in the older paleozoic rocks. The surface on which they were laid down was irregular and Lower Carboniferous is not always present. Within the Zwickau and Lugau areas, one finds the Saarbrück and the Lower Ottweiler, the Upper Ottweiler, if ever present, having been removed by erosion prior to deposition of the Rothliegende, which rest discordantly upon the Coal Measures. It is not easy to determine the boundary between Saarbrück and Ottweiler; Geinitz recognized three zones, marked by *Sigillaria, Calamites,* Ferns; later students, however, preferred to make only two, *Sigillaria* and Ferns, placing the limit about midway in the *Calamites* zone.

The Zwickau area is very small, not more than 20 square miles, but its coal seams are numerous and often very thick. These display in full all the peculiarities of limnic beds, variations in thickness, tendency to divide and to subdivide, frequent passage into shale and even into sandstone. The lowest persistent seam is the Planitz, which, at the southwest is practically single, but toward the northeast it is divided by increasing interval rocks and the three main benches become three seams, *A, B, C,* each of which has more than one local name. Near Planitz, the thickness is about 10 meters, the interval between *A* and *B* being less than half a meter; nearer Zwickau, the intervals are a half meter and two and a half; but, farther north, they become 40 and 15 to 30 meters respectively, the coal being 2, 4 and 4 meters in the several seams. The interval rocks are mostly sandstone. Toward the east and south, these seams are broken by so many partings as to be worthless, though they contain much good coal. In great part, the coal is bright Pechkohle, but it is often laminated or Schierferkohle and at times it passes into Russkohle, in which fusain (Faserkohle or Mineral Charcoal) predominates. The great Russkohlenflötz, at 40 to 56 meters above the Planitz, has an extreme thickness of 8 to 9 meters, almost wholly clean Russkohle. Toward the east and north, it breaks up into at least three seams, in which the Russkohle is often replaced with ordinary laminated coal. The coals of this lower

division, aside from the Russkohle portions, are, according to Mietzsch, coking. Geinitz states that the Planitz coal is of *Sigillaria* origin, while that of the Russkohlenflötz is derived from *Calamites*.

The higher zone has 7 seams of workable gas coal, 5 of which, one to three meters thick and yielding a caking gas coal, are practically exhausted. At best, their area was insignificant. The lowest two seams, Zach- and Schichtenkohlenflötz, are in larger area and each has a maximum thickness of somewhat more than 5 meters. Like the other seams, these divide and subdivide, the former toward the west and the latter toward the east. The total thickness of Coal Measures in the Erzebirge basins averages not far from 400 meters; that of the lower division, according to Mietzsch, varies from 40 meters in the southwestern portion to 80 and even 150 meters in the northeast, owing to inlaying of sandstones and conglomerates. The Rothliegende in these basins contains some worthless streaks of coal in the lower part.

The Döhlen basin or Becken des Plauenschen Grundes contains workable coal of Permian age, as determined in 1849 by Geinitz and Gutbier. Murchison[43] found the whole thickness of Lower and Middle Rothliegende between 800 and 900 feet. The conglomerates of the lower portion are gray, with blocks of granite, quartz and even of Coal Measures rocks. The coals are from Permian plants. These deposits, occupying a depression in Silurian rocks, consist of sandstones, conglomerates and shales, with, in the northern portion, a porphyry flow at the base. The color is mostly gray but variegated shale is present in the basal portion of the Middle Rothliegende. The coal seams are about midway in the Lower Rothliegende, within a mass of gray shale and sandstone, 20 to 30 meters thick. Geinitz mentioned four seams, of which the lower two are very thin. The third occasionally is thick but, for the most part, its coal is so dirty as to be almost worthless. The fourth or Hauptflötz is from 1 to 7 meters thick, the greatest thickness, as Hausse has shown, being in the deeper part of the basin; toward the border it becomes thin and impure. The partings are thin, but some of them are remarkably persistent. The coal is mostly laminated, but it often passes into Brandschiefer. The ash content is high, being,

[43] R. I. Murchison, " Siluria," 3d ed.. 1859, p. 345.

according to Dannenberg, 18 to 32 per cent., selected specimens having as much as 22 per cent. The water is from 4 to 8 per cent. A thin coal seam is present in the basal portion of the Middle Rothliegende, but is without value.

In all areas, the Rothliegende is unconformable to the Coal Measures. Fragments of Coal Measures rocks are common in the basal conglomerate and Siegert saw in the Lugau area large blocks of coal torn from exposed coal seams. Grains of coal occur commonly.

In 1881, Sterzel discussed the origin of coal seams and in 1901 a revised edition of his paper was published. He sums up in thoroughly judicial manner the features which, for him, appear to suggest autochthonous origin of the materials, and then presents the features which indicate allochthonous origin. These are:

(*a*) The often very distinct lamination of the coal; (*b*) the Bergmittel, which at times occurs abundantly within coal seams and consists of the same rock material as the Hangende and Liegende of the seam, is evidence of quiet deposition, as must be accepted for the plant material itself. Bergmittel may be in form of increased ash in the coal, or as conformable deposits, plates or benches of clay shale, or iron ore, varying in extent and often splitting the coal bed into an extraordinary number of thin plates. A new vegetation for each of these many thin coal layers appears inadmissable; (*c*) Stigmaria occurs frequently in the roof; (*d*) vertical stems in the roof of beds are only local and occasional. He concludes that the majority of facts speak for allochthonous origin of the Zwickau coal seams.

All observations lead him to the belief that the coal seams were formed in a lake basin, into which the plant material was carried from the widely extending swampy surrounding land, which was fitted for Waldmoors with luxuriant vegetation, as well as from the higher slopes, on which were plants, loving a drier region. The infloating was done by quiet waters, which carried very little inorganic matter. Plant materials predominated, so that great masses of more or less rotted organic matter were heaped up on the lake bottom, where afterward they were converted into coal. Occasionally, the watercourses were swollen and brought down rock material, which

formed partings, to be covered in succeeding time of quiet by a new deposit of plant stuff.

Periodically, perhaps because of crustal movements, notable changes came about in the fall of streams, leading to violent floodings. Then rock materials predominated and deposits of sand, mud and pebbles were formed, covering the plant materials, which are now the coal beds. Later came the period of quiet and the Waldmoor expanded to its former luxuriance. During the interval, many species of plants had been destroyed while others survived and new forms appeared. This doctrine of local change does not exclude changes in the lake bottom; that might be brought to a higher level, so that growth of plants might begin on it. Increased accumulation of detrital material in the lake would have the same effect. Perhaps, in some places of this sort, there grew the vertical stems, giving a local autochthonous formation.

Sterzel's conception closely resembles that presented by Grand-'Eury in 1882, which was abandoned by that observer after his knowledge had been increased by careful studies in regions aside from his own basin of St. Etienne. But the presentation is far from being conclusive.

Lamination of coal is by no means evidence that the material was transported; autochthonous peat, subjected to pressure, has the same structure. *Sigillaria* and *Lepidodendron* occur in roofs of coal seams; as *Stigmaria* is the rhizome of those plants, it ought to occur in roofs. Partings, such as those of coal seams, are familiar features of autochthonous peat deposits. Vertical stems are apparently rare and local in roofs, but there are vast areas of growing peat without trees, while there are other areas in which the Waldmoor condition prevails. It must not be forgotten that our knowledge of roofs is confined chiefly to exposures in mines, where the stems are only too abundant.

There is not much basis for the suggestion that a great lowland area, covered with Waldmoor, was the region surrounding the Zwickau lake. The Erzgebirge had been elevated prior to Carboniferous time and the Zwickau basin is at the foot of those mountains. Even if there had been a great Waldmoor area, it is inconceivable that streams meandering across it could bring down such great quan-

tities of macerated vegetable material. The density of vegetation in a Carboniferous Waldmoor was not inferior to that of a tropical jungle. Rain would have practically no erect on even loose plant stuff, while the meandering streams would remove little from their banks. Every one knows that such streams have great plumes of confervæ swinging from the banks, undisturbed year after year. It is difficult to conceive of crustal movements so abrupt as to cause floods, so sudden and severe as to sweep débris over the plain, to destroy the great Waldmoor and to leave no trace of the dense vegetation in the newly deposited rocks. It is equally difficult to understand why crustal movements should increase the water-supply. They would lead to rapid draining of the region but could not bring about terrific floods unless the rainfall were increased many times. In any event the floods would be mere floods, not devastating torrents, unless the Waldmoor area itself were distorted, in which case it would not be available for a new Waldmoor.

In 1903,[44] Sterzel described a *Sigillaria* stump, seen in the roof of the Zachkohenflötz. It was 1.25 meter high and tapered from 1.15 at base to 0.50 meter at top. The base was completely plane and the border was sharp. There is no trace of branching or of *Stigmaria,* as there should be if the plant were in place of growth. The stem evidently had been torn from its place by muddy water, robbed of its basal branching and then deposited in the roof of the coal seam. The softened base had become flattened under pressure. He states that the limit between coal and roof is "haarscharf" and that nowhere does the plant rise out of the coal into the roof. Sterzel's description shows that here is the familiar " Sargdeckel." The region is disturbed, the contact between coal and roof is sharp, neither is in its original relation to the other. The faulting explains the smooth base of the stump. Such stumps are not rare in roofs of the Zachflötz and Segen-Gottesflötz of Zwickau area.

Sterzel,[45] in a later paper, described a petrified forest observed in the Rothliegende of the Chemnitz region. The rich locality, near

[44] J. T. Sterzel, " Mitteilungen aus der Naturwiss.-Samlung der Stadt-Chemnitz," *Ber. Naturwiss. Gesells. Chemnitz,* t. XV., 1903, Separate.

[45] " Der versteinerte Wald," etc., the same, Band XVIII., 1913, Separate, p. 52.

Neuhilbersdorf, embraces about a square kilometer. The ground is full of petrified trees; beside prostrate, always fractured stems, large and small stems are seen as vertical stumps, apparently in the original place of growth. Silicified stems are shown at several places near Chemnitz. They are embedded in the marly beds of the Middle Rothliegende, on which, apparently, they grew.

He cannot accept the opinion that the trees while living were enveloped suddenly by the falling tuff and that they were silicified afterward. The plants are without bark and are broken across the stems. He believes that silification began during life of the trees and that it caused their death. The microscopic structure is as perfect as in living plants. All are conifers—*Araucarioxylon,* to which the leaves and twigs of *Walchia* seem to belong. Stems, 7, 10 and 20 meters long, are in the Chemnitz museum.

Thuringer Wald.—The Permian contains coal seams of workable thickness at several localities in Germany. For the most part, they have little interest, but the conditions in the Thuringian forest should be noticed. This area, bordering on Bavaria at the south, was visited several times by Murchison,[46] who states that in some valleys on each side of the Central Range there occur occasional outcrops of gray and dark colored shaly rocks, containing plant remains and at times seams of coal. These he regarded as belonging to the Upper Coal Measures of Germany. The coal is most abundant at the southerly end of the area, where it has been reached by shafts, which pass through a great thickness of Rothliegende. These Carboniferous beds were formed, he believes, during tranquil deposition, in marked contrast with the Permian beds, which were laid down during a time of great disturbance, marked by extrusion of much igneous material and by powerful translation of broken materials from preëxisting rocks. The coal-bearing deposits pass under cover toward the north.

Beyschlag,[47] writing many years afterward, stated that study of the central portion of the region is difficult as no good section is exposed. Eruptive rocks are abundant and sedimentary rocks

[46] R. I. Murchison, "Siluria," 3d ed., 1859, p. 332.

[47] Beyschlag, "Geologische Uebersichkarte des Thuringer Walden," *Zeitschr. d. d. Geol. Gesells,* Band 47, 1895, pp.. 596–607.

change abruptly in character as well as in thickness. Conglomerates prevail at the southeast, but in the middle and northwest portions the rocks are chiefly sandstones and shales. He assigns the whole section to Rothliegende, there being no Upper Coal Measures in the region. The succession is:

Upper	Tambacher beds	
Middle	Oberhofer beds	Lebacher beds
	Goldbauter beds	
Lower	Mansbacher beds	Cuseler beds
	Gehrener beds	

The Gehrener beds contain much eruptive matter and arkose; red and black shale with gray sandstone and breccia prevail; coal smuts and seams were seen near Gehren and a few other localities. The Mansbacher beds have no eruptives, the rocks being sandstone and clay shale with some thin seams of coal. At one time, six of these seams were mined. The flora of these shales was supposed to be that of the Upper Ottweiler (Stephanien), but it is predominantly Rothliegende, though containing many Ottweiler forms. *Walchia* occurs in sandy clay shale but never in the softer, plant-rich shales. The Goldbauter beds have much eruptive material in the western portion but none in the eastern. Midway in the section is a thin seam of coal. This is the highest, there being no coal in the Oberhofer or Tambacher beds.

Dannenberg[48] cites v. Dechen as stating that coal occurs in the Middle and Lower Rothliegende. The important locality is on the Bavarian border near Stockheim and Neuhaus, where a seam, 2.90 to 29 meters thick, is mined. When very thick, the coal is notably dirty, but washing removes most of the impurities and the coal, thus treated, is an excellent fuel. The output of washed coal in 1911 was 50,000 tons and plans were under way to increase it to 240,000.

The Pfalz-Saarbrück-Lorraine Coal Field.—This, known as the Saarbrück basin, is comparatively insignificant in area but is amazingly rich in the number and availability of its coal seams. The space, in which seams are exposed or under reasonably thin cover, is

[48] Geologie der Steinkohlenlager, p. 229.

rudely triangular, about 20 kilometers wide on the Saar River and diminishing northeastwardly to 10 kilometers at a little way beyond Neukirchen, 50 kilometers from the Saar. The extreme distance, along which the coal is accessible, is barely 100 kilometers, extending from beyond the eastern border of Lorraine across the narrow strip of Prussia into the Rheinpfalz of Bavaria. The field has been described more or less in detail by many students, but use will be made here only of works by Nasse,[49] v. Ammon and Dannenberg. Nasse and Dannenberg have discussed the whole basin, while v. Ammon has described in detail the Bavarian field, which embraces the greater part of the available area.

The deposits occupy a trough, much distorted, which is cut off abruptly at the south by the südliche Hauptsprung, a downthrow of not less than 1,000 meters. Only Permian and Carboniferous rocks have been found within the trough, but Bunter Sandstein is present just beyond the immediate area. The lowest beds reached by borings are Saarbrückian, which are succeeded by Ottweiler and Rothliegende in conformable order, so that the whole may be termed the Permo-Carboniferous system; but in the extreme western portion, within France, there is unconformity, for there Rothliegende rests on disturbed Saarbrückian beds. The latest classification is Rothliegende, Upper, in four divisions, of which the Lebacher beds are

> the lowest. This contains plants, Estheria, reptiles, fishes and worthless streaks of coal. Lower, the Kuseler beds, containing similar fossils, some calcareous beds and streaks of coal.

Upper Carboniferous,

> Ottweiler beds. Upper, containing fish remains, etc., with Breitenbach coal bed. Middle, or Potzburg beds, with some calcareous beds, *Leaia, Cardinia* and the Hirteler coal seams. Lower, the Hangende Flötzzug, fossils as in Middle; Holzer Conglomerate at base.
>
> Saarbrück beds. Upper or Flammekohlen Gruppe, Lower or Fettkohlen Gruppe.

[49] R. Nasse, " Geologische Skizze des Saarbrücker Steinkohlengebirge," *Zeitsch. Berg-hutten-Salinen-wesen im Preuss.,* Band 32, 1884, Abh., pp. 1–89; L. v. Ammon, " Die Steinkohlenformation in den Bayerischen Rheinfalz," München, 1903, pp. 1–106; A. Dannenberg, " Geologie der Steinkohlenlager," pp. 105–165.

Lower deposits are unknown and it is uncertain whether or not the Waldenberg (Sudetic, Lower Westphalian) and Lower Carboniferous are present. The rocks are of limnic origin; no marine forms have been observed.

Dannenberg gives the thickness of Rothliegende as not less than 2,000 meters, that of Ottweiler as 1,500 to 2,000 and of Saarbrück as 2,500 to 3,000 meters. Nasse estimated that Ottweiler is 1,700 to 2,000 in the area between Saar and Blies Rivers, but 3,000 in the eastern portion within Bavaria; the Saarbrück, on the contrary, become thinner toward the east, being 3,200 on the Saar but only 2,100 on the Nahe River. Borings in later years have proved that, while it is true that Ottweiler increases notably toward the east and that Saarbrück decreases notably in that direction, the variations are not so great as Nasse believed. It is very clear that influx of material for Saarbrück was from the west and for Ottweiler from the east, the coarse deposits for the latter being on the east side, while in the former they are on the west side.

The number of coal seams, according to Dannenberg, is not far from 400, of which 150 to 160 are workable, that is to say, are more than half a meter thick. Nasse showed that these are grouped into " Flötzzuge," separated by practically barren intervals. The coal seams of the Rothliegende and Ottweiler are not important and only insignificant seams were formed above the Kuseler beds. There were serious extrusions of igneous rocks in the earlier Saarbrück and in the closing portion of the Upper Rothliegende.

Thin coal is present in the Lebacher beds, which are mostly yellow sandstone and dark shales; in the western portion, the shales have fish remains and iron ore, but the ore is wanting at the east. The flora, according to Nasse, consists almost wholly of Rothliegende forms, with very few of Coal Measures type. The Upper Kuseler rocks are mostly gray shales and sandstones; coal seams were observed at many places; one, the Kalk-kohlen Flötz, has a limestone roof and occasionally becomes 47 centimeters thick; another, near the base, the Muschel-kohlen Flötz, is from 15 to 20 centimeters thick and its shale roof has abundant *Anthracosia*. The Lower Kuseler consists chiefly of gray and red sandstones, variegated shale and thin layers of limestone. Fish remains have been

obtained at several horizons and the flora is rich in Rothliegende forms, among them, *Callipteris conferta*. With these are many Coal Measures species, but no *Sigillaria* or *Stigmaria*.

The Upper Ottweiler, about 125 meters thick, has mostly grayish deposits, laminated shales and micaceous sandstones. In Bavaria, it has the Breitenbacher or Hausbrandflötz, 12 to 30 centimeters thick, which is mined by stripping at many places, as the coal is an excellent domestic fuel, being maigre, smokeless and without clinker. The flora is mingled Saarbrück and Rothliegende; Weiss, quoted by v. Ammon, has described it as a "prevailingly stone-coal flora; *Stigmaria, Sigillaria* and *Lomatophloios* still abundant, ferns numerous, *Walchia* rare." Animal remains are few, chiefly insects and crustaceans. The Middle Ottweiler is a thick complex of mostly red sandstone and conglomerate, with red, bluish and yellow shales. The conglomerates, according to Nasse, are not constant but are lenses. The Hirteler coal seams are unknown in Bavaria but are present near Saarbrück in Prussia. Fossil plants are not abundant and such as do occur are indefinite, but silicified wood is not rare. v. Ammon states that the mass is 800 meters thick near Saarbrück, but near Dudweiler in Bavaria it is 950. The Lower Ottweiler, formerly regarded as Upper Saarbrück, about 800 meters in western part of the basin, contains much red rock, gray, reddish and greenish shades and sandstones. Its base is the Holzer conglomerate, which is characteristic at the east but becomes insignificant toward the west. Over it are the *Leaia* shales, which enclose thin layers of limestone and underlie the Hangenden Flötzug, consisting of gray and some red sandstone and shale with two or three variable seams of coal. The thicker seams, Lummerschieder and Walschieder, are of workable thickness in the Prussian area but become insignificant or disappear toward the east in Bavaria. At Frankenholz, 5 coal streaks were found but at Dittweiler, farther east, no trace of coal was found in the boring. The thickness in the Prussian area is not far from 1,000 meters and is considerably more in Bavaria.

The Saarbrück is divided into the Upper or Flammekohlengruppe, yielding a sintering coal, and the Lower or Fettkohlengruppe, from which coking coal is obtained. Conglomerates are numerous, especially in the western portion, where, according to

Nasse, there are beds more than 40 meters thick. The pebbles are mostly of quartz but other rocks are represented. The shales are gray to blackish, but some beds are red or green. The flora, according to Weiss, cited by v. Ammon, is a "Steinkohlen flora, with many *Sigillaria* and lycopods as well as ferns." v. Ammon states that *Walchia pinniformis,* characteristic of the Lower Rothliegende, occurs sporadically. The Schatzler beds of the Lower Silesian basin have a flora like that of the Lower Saarbrück.

Within Bavaria, the Upper Saarbrück coals are mined at Frankenholz and Consolidated Nordfeld, both in the eastern portion. The group is divided into Upper and Lower, the former being worked at places named. Twenty-five coal seams have been discovered, of which more than half yield a gas coal while the others have Flammekohle. The screenings of each are mixed with Fettkohle in manufacture of coke. The seams show great variation within Bavaria; several, which are important at some localities, become unworkable or disappear within short distances. The seams become thicker toward the west. Kliver, cited by Dannenberg, states that at or near Jaegersfreude there are 10 workable seams, 21 which are too thin for working under present conditions and 101 which are mere streaks; in all, 132 with 32 to 33 meters of coal. Some seams are from 3 to 5 meters thick, but they are broken by partings into several benches. The lower division is less important, having only 3 or 4 workable seams, though the whole number of seams is about 40. At one time it was believed that this division thinned away toward the east, but this opinion has not been confirmed by the later observations.

The Lower Saarbrück or Fettkohlenpartie yields coking and gas coals. The number of seams and the coal content increase from east to west. This division is mined in the Pfalz region within the St. Ingbert and Mittelbexbach areas, where three groups of coal seams exist. The upper, about 537 meters thick, has 40 seams; a barren space of 63 meters separates it from the middle or Rothhell, 240 meters thick and containing 19 seams; at probably 300 meters lower is the bottom group, discovered in a boring within the Rischbach Valley, which has 12 thin seams. The rocks of Lower Saarbrück are coarse, there being much sandstone and conglomerate.

The coals of the highest group vary from Fettkohle to Flamme-kohle; a single seam may yield both kinds. The Rothhell consists of gray shales, hard sandstones and conglomerates with an occasional red bed. The coals are important at St. Ingebert, but westwardly they decrease and are insignificant at the Saar River. The Rischbach seams appear to be merely local, having been found only in a boring and a shaft within the Rischbach Valley.

In the Mittelbexbach area, 10 seams with 9 meters of coal are mined. They belong to the highest group and yield only Flamme-kohle, which is an admirable domestic fuel. The mines are near the südliche Hauptsprung, where the strata are seriously disturbed. The seam, Number 3, has an interesting structure in one mine. It consists of coal, 0.04; parting, 0.20; coal, 1.20. The thin bench on top is much broken by overthrust faults, which involve the parting, but the main coal is practically undisturbed. This upper group of the Lower Saarbrück becomes extremely important in the vicinity of Saar River, where there are 40 workable seams with 50 to 60 meters of coal. Cannel is present occasionally but it is unimportant. At one place it is the highest bench; at another it is the lowest.

Nasse, in discussing the character of coal seams, states that in this basin a seam one meter thick is rarely without partings, but he mentions one, 4.08 meters, which yields clean coal throughout. Variation in thickness is the rule; mere streaks become important seams, which may thin away to disappearance. The intervals are uncertain, so that seams widely separated at one locality may be united at another. Very often the roof is Brandschiefer, a coaly shale, which is combustible. When sandstone or conglomerate is the roof, the upper part of the seam is irregular; but the bottom rarely shares in this irregularity.

The Ruhr Basin.—Several coal basins are in northwestern Prussia, which are of moderate extent but, in some cases, economically important. The Ruhr, Lower Rhine or Westphalian basin lies east from the Rhine along the Ruhr, Emscher and Lippe Rivers; the cities of Essen, Bochum and Dortmund are on the northern border. The area is not far from 3,200 square kilometers, but the thickness and quality of coal render it one of the most important on the continent. The outcropping portion is south from the cities mentioned,

but borings prove that the coals persist northward beyond the Lippe under increasing cover and that, in like manner, they are present west from the Rhine. The region has been studied carefully by Dannenberg,[50] who has supplemented his observations by those of other geologists.

The Lower Carboniferous (Dinantien) is shown on the eastern border, where it is succeeded by the Flötzleeren Sandstein (Namurien or Lower Westphalian), which apparently is without coal and is taken to be the equivalent of the Millstone Grit, the Sudetic of eastern areas. This is followed by the Productive Coal Measures, equivalent to Saarbrück (Upper Westphalian), as well as to the Lower and Middle Coal Measures of Great Britain. It is the important group. The Ottweiler, Stephanien of France, is apparently absent. Permian is represented almost wholly by the Zechstein, Rothliegende having been observed in only a few petty, isolated patches. The Saarbrück is in four divisions, which, in descending order, are:

	Volatile.	Chief Seam.	Thickness.
Gasflammekohlen......................	37–45	Bismarck	1,000 m.+
Gaskohlen...........................	33–37	Catharina	290–300 m.
Fett- and Esskohlen	20–33	Sonnenschein	600–885 m.
Magerkohlen.........................	5–20	Mausegatt	1,050 m.

There are variations in the conditions for, chemically, the coal of a seam is not the same throughout its extent. Beds of the Magerkohlengruppe at times yield coking coal; among the Fettkohlengruppe, some give gas coal while coking coal is obtained from several seams in the Gaskohlengruppe. Generally speaking, the volatile content increases from west toward east, as does the thickness of the seams. Conglomerate and ironstone are common in the Magerkohlen, less so in the middle divisions, but are abundant in the upper. Marine deposits are frequent in the lowest division, but become fewer above, where fresh-water fossils are the usual forms.

The Magerkohlengruppe is practically barren in the lower 250 to 300 meters, there being only thin seams, some of which are workable locally. The next portion, reaching to the Hauptflötz, has at

[50] A. Dannenberg, "Geologie der Steinkohlenlager," 1908, pp. 49–79.

least two workable seams and is 100 meters thick. The Hauptflötz and the Wasserbank, 80 meters lower, have well-marked marine roofs; between the Hauptflötz and the Mausegatt, 250 to 300 meters, coal seams are few and but locally workable; the Sarsbank, about midway, has a marine roof. The next interval, 100 to 150 meters, has four or five workable seams with 3 to 4 meters of coal and contains much iron ore, which was mined in earlier days. It has three beds with fresh-water fossils. The highest interval, about 300 meters, is almost barren, having few and rarely workable seams. The most notable feature is the rich marine roof of the seam Finefrau-Nebenbank near the base of the interval. This Gruppe ends with a well-marked conglomerate, 10 to 20 meters thick.

The Fettkohlengruppe, from the Sonnenschein to the Catharina, averages about 600 meters, but the mass increases toward the east, coal increasing in the same direction from 23.6 to 35.85 meters. Clay shales predominate, sandstone is rare and conglomerate is unknown. Ess- or Schmiedekohle, with about 20 per cent. of volatile, predominates in the lower part, but in the upper part the volatile becomes 33 per cent. and the coal is caking. The coal seams tend to divide, detracting from their value. Catharina alone is easily identified in a considerable area, as it has a marine roof.

Changes in most of the seams are so abrupt that tracing is impossible; mere smuts suddenly become workable seams and as suddenly become worthless again.

The Gaskohlenpartie is almost barren in the lower half, but the upper portion has about 10 workable seams with 8 meters of coal. The lower part has a seam of cannel, 47 centimeters thick. Changes in chemical composition of coal in individual seams are frequent. No marine forms have been discovered except at the very base, in the roof of Catharina.

The Gasflammekohlengruppe has 25 seams more than 50 centimeters thick. Clay shales predominate in the lower half and the coal seams are much less variable than those in the upper half,. where sandstone and conglomerate prevail. Chemically, the coal varies notably; in extensive districts, only gas coal is found. Cannel occurs frequently; one seam has 1.36 m. as the upper bench and 1.37 m. as the lower.

There is every reason to believe that the Ruhr basin is continuous under cover with the Aachen basins at the west; it may be continuous also with the Limbourg area of Holland and the Campine area of Belgium, in both of which the coal is deeply buried and its existence has been proved by borings.

The Aachen Basins.—These, often referred to as the Westphalian basin, embrace, according to Dannenberg,[51] two areas, the Würm- (or Worm-) Revier, north from Aachen, separated by a strip of Upper Devonian from the Stollberg-Eschweiler Revier, southward from that city. The latter is known also as the Inde-Becken.

The Würmrevier, locality of oldest coal mining operations on the Continent, has not less than 45 coal seams in the western portion, of which 11 have been exhausted. Of the others, 14 are workable with 12.5 meters of coal, the lowest being the Steinknipp, about one meter thick. The disturbance in this portion was extreme and the coal is in great part anthracitic. Dannenberg notes that these coals are at horizons, which, in the Inde basin, have coals much richer in volatile. He suggests that the change was not due to disturbance alone but possibly in part to lack of thick cover. In the eastern portion, where disturbance, though severe, is less than in the western, one finds coking coal with 16 to 24 per cent. of volatile, and non-coking coal with 15 to 17 per cent. The remarkable horizon is the marine roof of Bed 6 at the Marie mine. The Flötzleeren Sandstein has not been recognized in this area.

The Inde-becken or Eschweiler revier has the succession complete from Lower Carboniferous to and including the Saarbrück. The boundary between Lower Corboniferous and Coal Measures is sharp, there being no passage beds between the limestone below and the sedimentary rocks above; yet there appears to be complete conformity. A mass, almost wholly sandstone and 800 to 1,000 meters thick, rests on the limestone. This, practically barren, as it contains only two or three unworkable seams of coal at 150 to 200 meters above the base, seems to be equivalent to the Millstone Grit. The Productive Coal Measures, somewhat thicker than the barren measures below, have two groups of coal seams, the Aussenwerke and

[51] A Dannenberg, " Geologie der Steinkohlenlager," pp. 83–101.

the Binnenwerke, separated by an almost barren interval of several hundred feet. The relations of the lower group, the Aussenwerke, cannot be determined satisfactorily owing to lack of distinct flora and fauna; it may be equivalent to the lower division of Würm, in which a marine deposit is roof of Marie number 6. But the Binnenwerke is unquestionably Saarbrückian or Upper Westphalian. Forty-five coal seams have been recognized, none of them thick. In the western portion of the workable seams, only 2 ever exceed 1 meter, 5 never exceed 75 centimeters and 9 are less than 60 centimeters. The Aussenwerke seams are thin.

The disturbance is much greater in the eastern part of this basin than in the western, but the coals are same, chemically, in both. Binnenwerke coals are caking and their coke is good, but that from the Aussenwerke is sintering. Five conglomerates are persistent; two of them, thick and coarse, are in the Flötzleere, above and below the coal seams; the third is just below the Aussenwerke and is an important stratigraphical horizon; the fourth is just above that division and the fifth, comparatively fine-grained, underlies the Padtkohl or lowest seam of the Binnenwerke.

Belgium and Northern France.

Some prongs of the Aachen Coal Measures reach into Belgium, but exposures end quickly and a space of about 20 kilometers, covered by later deposits, intervenes between the last Aachen outcrop and the first Belgian mines. Within Belgium, Coal Measures remain in the Dinant trough, at the south, but the basins are isolated, very small and without interest. At the north is the extensive Campine area, continuous with that of Limbourg in Holland, but that is known mainly through records of boring, as mining operations were begun very recently. Actual work is confined to the great Haine-Sambre-Meuse trough, which extends from the Prussian border across Belgium into the Department du Nord of France; it is interrupted only by a narrow barren space in the Samson Valley, which divides the Belgian area into the Liége basin at the east, including the Herve, Liége and Andenne districts, and the Hainaut basin at the west, embracing the Basse-Sambre, Charleroi, Centre and Couchant-de-Mons districts.

The succession in Belgium is sufficiently clear, though, owing to the extreme distortion along the southern border, some localities remain, in which relations are somewhat uncertain. The order as given by Renier is

Stephanien   Absent

		⎧ Assise de Flénu (Renier)
		⎪ Petit-Buisson
Westphalien	Supérieur ⎨	Assise de Charleroi (Stainier)
		⎪ Gros-Pierre = Stenaye
		⎩ Assise de Chatelet (Stainier)
		Poudingue houiller
		⎧ Assise d'Andenne (Stainier)
	Inférieur ⎨	Veine aux Terres
		⎩ Assise de Chokier (d'Omalius)

Dinantien or Lower Carboniferous.

This is equivalent to the grouping presented by de Lapparent and Munier-Chalmas. Stainier prefers to limit the term Westphalien to the upper three assises and to apply the name Namurien to the lower part of the section. This nomenclature has been accepted by Dannenberg in his description of the Belgian fields. The coal seams, Petit-Buisson, Gros-Pierre and Veine-au-Terres are at or very near the base of the several assises. The number of marine horizons decreases upward; it has been suggested that some relation may exist between quality of coal and the origin of the rocks; Chokier, essentially marine, is wholly barren; Andenne has marine horizons and little coal, which is true also of Chatelet; but Charleroi, without positively marine deposits, is rich in coal; Flénu has but one marine deposit, that in roof of Petit-Buisson at the base, and this assise has much coal.[52]

Formerly, the Coal Measures were divided into H1, *a, b, c,* and H2, the former being the Namurien, the latter being the Westphalien or upper Westphalien. The general features of the lower division were described by Purves.[53] The Chokier, or basal assise, is a mass

[52] These details are mostly from A. Renier, " Les gisements houillers de la Belgique," *Ann. Mines de Belg.,* t. XVIII., 1913, pp. 757, 759, 767, 773.

[53] J. C. Purves, " Sur le delimination, etc., de l'étage houiller inférieur de la Belgique," *Bull. Acad. Roy. Belg.,* III., t. II., 1881, sep., pp. 1–57.

of shale, 10 to 70 meters thick, increasing toward the west. The middle portion, the Andenne of Stainier, is 130 to 400 meters, increasing, as the Chokier, toward the west. It has thin streaks of terroulle or earthy coal, one of which, near the base, has been mined; it has a sandstone roof containing *Calamites* and is 40 centimeters thick; it has a true underclay, with *Stigmaria*. A persistent band of ripple-marked sandstone, 5 to 10 meters thick, overlies the coal-bearing shales and a marine deposit is near the top of this division. The Grés grossier, or Poudingue houiller, the Poudingue de Monceau-sur-Sambre of Mourlon,[54] at top of the Namurien, 12 or more meters thick, varies from fine sand to coarse conglomerate.

Dannenberg says[55] that in the Liége district the Andenne has three seams, of which the middle one, V. au Gres, is the best; that at the base, V. aux Terres, is so dirty as to be worthless. Stainier[56] states that, in the Andanne or eastern district of the Liége basin, the Chokier consists chiefly of dark laminated shale, utilized in manufacture of alum. The Andenne, mostly shale, has the lowest coal seam at 80 to 130 feet meters above the Lower Carboniferous limestone. It is thin, without value, and underlies a sandstone, often 20 meters thick. On this rests a mass of shales containing the only workable seam, known as Plateur-de-Rouvroy, Pélémont, Six-Mai and Grande Veine, which at times is one meter thick, though usually between 50 and 60 centimeters. It is terroulle, an intimate mixture of coal and clay, burning slowly and without flame. Almost invariably it is in two benches, one giving fine, the other lump coal. At the western extremity of the district, this seam divides, but the benches retain their character. The roof is marine in the eastern portion, containing *Lingula* and *Loxonema*. The poudingue houiller has beds of conglomerate with pebbles, at times, of one decimeter diameter; it would seem that these conglomerate layers are merely lenses.

Smeysters[57] notes that, in the eastern part of the Hainaut basin, the lower Westphalian has an extreme thickness of 350 meters, but

[54] M. Mourlon, "Géologie de la Belgique," 1880, t. i. p. 119.

[55] Geologie der Steinkohlenlager," p. 280.

[56] X. Stainier, "Bassin houiller d'Andenne," *Bull. Soc. Belg. de Geol.*, t. VIII., 1894, Mem., p. 3–22.

[57] J. Smeysters, *Ann. Mines de Belg.*, t. V., 1900, pp. 1–128.

it decreases toward the east, becoming only 150 beyond Namur. Three coal seams are in the middle stage (Andenne), all of which are mined locally in the eastern part of the basin. *Calamites* and *Stigmaria* are abundant. A thin coal seam near the top has a marine roof. Conglomerate is of only sporadic occurrence in the Poudingue houiller.

Stainier,[58] in the Charleroi and Basse Sambre districts, found the equivalent of the Andenne Plateur-de-Rouvroy in the Veine du Calvaire, which is 50 to 60 centimeters thick; it has been mined for many years. This bed is at 110 meters below the Poudingue. The lowest seam, Fort d'Orange, is half a meter thick and yields an excellent coal of the terroulle type, its composition being: volatile, 10.5; fixed carbon, 84.34; ash, 5.16. The coal seams are all very thin in Charleroi and a similar condition exists in Couchant de Mons. Cornet[59] has shown that the Chokier fauna in the latter district is wholly marine, but of littoral type. The deposits are fine-grained, but he shows that this is no proof of deep water, for the great proportion of the forms are mollusks with byssus. Seventy per cent. of the Coal Measures deposits are fine material. He is convinced that lowland surrounded the area of deposition.

The Westphalian (Upper Westphalian) has, in ascending order, the assises of Chatelet, Charleroi and Flénu.

The Chatelet is poor in coal and the seams are thin, though less irregular than those of the Andenne. In the Liége district, two seams are worked, Chesson and Grande Pucelle or Désirée, 70 and 60 centimeters thick.[60] The former has a marine roof, which Dannenberg believes equivalent to that of Ste.-Barbe-de-Floriffoux in Charleroi district and very probably to that of Breitgang in Eschweiler, Finefrau-Nebenbank in Ruhr. The coal of Grande Pucelle has 16 per cent. of volatile at the south, but only 6 per cent. in the northern, the less disturbed portion of the district. Very little of the Chatelet remains in the Andenne district and but one seam is mined. This, the Chenevis, at 120 to 160 feet above the poudingue

[58] X. Stainier, " Stratigraphic, etc., de Charleroi et de la Basse-Sambre," *Bull. Soc. Belg. de Geol.,* t. XV., 1901, Mem., pp. 1–60.

[59] J. Cornet, " Le terrain houiller sans houille (H1 *a*)," *Ann. Soc. Geol. de Belg.,* t. 33, 1906, Mem., pp. 139–152.

[60] A. Dannenberg, op. cit., p. 280.

houiller, has a typical mur and the toit is rich in plant remains. Stainier[61] thinks that the poverty of the Chatelet in the Hainaut basin is remarkable, there being only one generally workable seam, though some veinettes are mined locally. The V. Leopold. known under many names, is 100 to 140 meters above the poudingue and attains workable thickness at numerous places. At 50 meters higher is the V. Ste.-Barbe-de-Floriffoux, which is thickest midway in the basin, where it is in two benches, 10 and 40 centimeters, separated by a shale parting of 80 centimeters, and yields a coal having volatile, 17; fixed carbon, 68.72; ash, 14.28. The mur is white, silicious, with *Stigmaria*, and is from 0.30 to 1 meter thick. It bears great resemblance to the English ganister. The roof is black laminated shale with marine fossils. Stainier has described at least six horizons of fossils, one of them unmistakably marine, the others probably brackish water. The Chatelet coal seams become wholly unimportant toward the west.

The Assise de Charleroi is divided in the Liége district into St.-Gilles, Liége and Seraing faisceaux, 200, 350 and 400 meters as extreme thicknesses. The coal seams are 9, 14 and 13. All are thin, rarely reaching one meter, but the Grande Maret, at base of the Liége faisceau, averages 1.80 and sometimes reaches 2.12 meters; it has three partings, 77 centimeters, and is the only seam in this faisceau which is mined systematically; the Grand Bac, next above it, is mined at some localities. Only two seams of the Seraing, the Stenaye at base and the Houilleux next above, are worked; but these are exceedingly variable. The marked marine horizon in roof of Grand Bac is thought by Dannenberg[62] to be equivalent to that over Coal 6 of Mine Marie in the Aachen and that of Catharina in the Ruhr basin. He correlates Charleroi with Saarbrückian.

Charleroi deposits have been removed from the Andenne district but they are important in the Hainaut basin. Stainier finds three faisceaux, Sablonniére, des Ardennoises and Goufre. The upper part of the Sablonniére is no longer accessible, but there are six workable seams and several streaks in the lower portion. Almost all of them have a faux-toit, sometimes cannel-like, and are divided

[61] X. Stainier, *Bull. Soc. Belg. Geol.,* t. VIII., 1894, pp. 17, 20.

[62] A. Dannenberg, op. cit., p. 284.

into benches.   The lowest seam, like Ste.-Barbe-de-Floriffoux, has the *en chapelet* structure and shows extraordinary changes in thickness.   The middle faisceau has 16 seams, 0.45 to 1 meter thick, many of which have a faux-toit of gallet, or of shale and coal, and a typical mur.   The roof in some cases contains *Naiadites* and *Carbonicola*.   One seam has *en chapelet* structure; intervals between seams vary, apparently without rule.   The Goufre or lowest faisceau is the most important, having 10 workable seams, 4 of them more than 1 meter thick, and all more regular than those of des Ardennoises.   The highest seam, V. Anthracite, is often absent, having been removed during deposition of the overlying sandstone, which occasionally reaches almost to the V. Caillette, 3 meters below. V. Anthracite is seldom thicker than 30 centimeters and its coal has but 8.80 per cent. of volatile, much less than that in any seam below it.   The V. Tatonie has sandstone pebbles and is very close to the underlying Grés de Hamm, which is 10 to 12 meters thick and closely resembles the poudingue houiller; like that, it contains grains and pebbles of bright coal.   The thickest seam, Dix-Paumes, has 1.28 meter of coal on the north and south sides of the basin, but is much thinner midway.   It contains pebbles of quartzite and fragments of gallet, a cannel-like shale.   The coal is excellent, with 16.1 per cent. of volatile and only 3.5 of ash.   V. Gros-Pierre, Stenaye of the Liége district, is irregular, usually present at the east but disappearing toward the west.   It has, at most, 0.93 of coal in 4 benches; its coal has a fibrous structure and frequently contains pebbles of quartzite. Its thin faux mur rests on sandstone, which has *Stigmaria* in the upper part.   A cross-bedded sandstone is persistent in the faisceau Goufre.   The conditions farther west in Hainaut are not materially different from those already described.

The Flénu deposits are confined practically to the district of Couchant de Mons, in much of which the coal is buried deeply, but mining operations are extensive.   The coal is much richer in volatile than that of the Charleroi but peculiarities of seams and of the interval rocks are much the same.   The lowest seam[63] is the Petit-Buisson, which has a well-marked marine roof, whence Cornet ob-

[63] J. Cornet, "Seconde note sur les lits a fossiles marins," etc., *Ann. Soc. Geol. Belg.*, t. XXXIV., 1907, Bull.., p. 93.

tained *Orthoceras, Lingula, Pernopecten* and *Carbonicola.* Renier[64] states that this coal seam was covered by ocean water soon after deposition, so that at some localities it has been replaced with dolomite. This dolomite encloses the vegetable pulp of the swamp, little changed.

The mass of deposits decreases toward the east. Andenne from 340 to 170 meters; Chatelet, from 400 to 288; Charleroi is 1,270 in Couchant de Mons but only 970 in the Liége district. Four coal seams at most are in the Andenne; the same number in the Chatelet, but they are unimportant except in the Liége district; Charleroi is rich throughout, having 19 workable seams in Couchant de Mons with 10.70 m. of coal, 20 in Charleroi, with 16.85 m., 23 in Liége with 17.45 m. of coal. Flénu in Couchant de Mons has 45 seams with 27.20 m.; besides these, each more than 30 centimeters thick, there are many veinettes, which rarely become thick enough for local operation.

Intervals between coal seams vary almost capriciously. Smeysters[65] notes many instances in the eastern part of Hainaut basin; one may mention here only that between the Mere-de-Veines and the Crevecœur. This interval is usually 10 or 12 meters, but at one locality, it is reduced to 60 cm., yet within a short distance the normal interval was observed. The coal seams are equally variable and some of them, as mentioned by Stainier, resemble a string of huge beads. Several seams are persistent enough to be utilized as horizons, but great variability characterizes all.

Many years ago, Cornet[66] grouped the Belgian coals into (1) houille maigre à longue flamme ou houille flénu; (2) houille maigre à longue flamme ou demi-grasse; (3) houille grasse maréchale ou houille grasse; (4) houille sèche à courte flamme ou houille maigre. (1) is brilliant, with conchoidal fracture, ignites readily, yields much illuminating gas, but the coke is not well fused; (2) has shaly fracture, often has fusain, yields excellent but not strong coke; (3) gives a coke good for all purposes; while (4) burns slowly and the coke is

[64] A. Renier, " Les relations géologiques du Bassin houiller du Nord de la France avec les gisements belges," *Bull. Asoc. Ing.,* Fasc. 1, 1919, p. 18.

[65] J. Smeysters, *Ann. des Mines,* t. V., 1900, pp. 103–106.

[66] F-L. Cornet, " La Belgique Minerale," *Catalogue of Paris Exposition,* 1878, Separate, pp. 18–25.

not fused. He remarks that the volatile decreases downward in the measures but he notes also a variation along the direction of strike and still more notable decrease from the disturbed southern area northward into the slightly disturbed area along the northern border.

Renier[67] offered a somewhat different grouping; Flénus, with more than 25 per cent. of volatile; Gras, with 25 to 16; Demi-gras, with 10 to 11 and Maigre, with less than 11. Gallet, resembling bituminous shale, is closely allied to cannel. The different benches of a seam are often unlike in volatile content and there are local variations which are puzzling. At the same time it seems possible to find a law of variation in order of superposition; equally so in a single seam along general direction of the trough, or even in a direction normal to the line of the trough. The downward decrease is thus, Flénu, maximum, 35 per cent.; Charleroi, 24; Chatelet, 18; Andenne, 15. But in the Flénu, the volatile varies from 25 to 35; in the Charleroi, from 17 to 20 within Couchant de Mons, 17 to 18 in Centre, 10 to 18 in Charleroi, 13 in Basse-Sambre, 0.5 to 21 in Liége district; the Chatelet from 6 to 10 and the Andenne from 7 to 15.5. He thinks that Hilt's law is practically applicable to the Belgian area. But the volatile increases from north to south, that is, from the less disturbed to the intensely distorted area. Finally, the volatile decreases from the outcrop toward the deeper part of the basin.

Dannenberg,[68] utilizing tables of analyses compiled by Stainier, makes clear that, in the Liége district, the volatile of the respective faisceaux of the Charleroi decreases downward from 23.7 in the upper St. Gilles to 6 per cent. in a seam near base of the Seraing. But there are exceptional seams; one in the upper Liége faisceau has abnormally low volatile, being anthracite, while one in the upper portion of Seraing has 24 to 25 per cent. and is the richest gas coal in the district. More important are the variations across the basin from north to south. In the northern portion, the " Plateurs," where disturbance is comparatively slight, the percentage is low, but it increases greatly in the southern portion, where the disturbance

[67] A. Renier, op. cit., 1914, pp. 23–30.
[68] A. Dannenberg, op. cit., p. 285.

was extreme. In four important seams of the faisceau Seraing, the percentages at the north are 13, 7.3, 6.2, and 6, but these increase southwardly to 20.8, 18, 15.5, 16.6.

France.—Passing into the Department du Nord in France, one reaches the Valenciennes basin, which is continuous with the Hainaut basin at the east and with that of Pas-de-Calais at the west. According to Barrois, the Coal Measures come to the surface in a comparatively small area near the Belgian border but elsewhere they are largely covered by later formations, so that mining operations were begun at much later date than in Belgium. During Trias, Jura and Lower Cretaceous time, the Coal Measures were exposed, and erosion removed them from a great area. The limits of the coal deposits have been determined approximately by borings, but the region has been disturbed so seriously by folds and overthrust faults, especially along the southern border, that the succession can not be determined beyond doubt. The basin is from five and a half to sixteen kilometers wide. The coal seams are numerous, fairly uniform, but are thin, rarely exceeding one meter and averaging about 70 centimeters; under favorable conditions, some only 35 centimeters thick, have been mined. The actual number of workable seams can hardly be determined; Olry attempted to ascertain it. Going from north to south, he found in the several faisceaux, beginning at the bottom,

A, in the northern portion,

faisceaux 1, 2, 3, 35 seams; 4, 31 seams; 5, 36 seams;

B, in southern portion,

6, 25 seams; 7, 16 seams; 8, du Marly, 3 seams, in all 146 seams. But paleontological work by Barrois and Paul Bertrand[69] has proved that this number is much too great. The seams appears to be superimposed as Olry supposed them to be, and the change in chemical composition is singularly regular in the order; but certain seams have been recognized in both portions of the region, though differing in facies and in composition. Barrois states that the seams of faisceaux 1 and 8 must be ignored, that faisceaux 5 is superimposed only

[69] C. Barrois, "Exposé de l'etat de connaissance sur la structure géologique du bassin houiller dans le Department du Nord," Lille, 1909, pp. 1–22.

in part upon 4 and so has only 15 seams. The number of workable seams does not exceed 77 and even that estimate may be excessive. The zone of Flines, equivalent to Andenne of Belgium, gives evidence of at elast five invasions by the sea.

The Concession of Dourges was studied many years ago by Breton.[70] He recognized a general decrease in volatile downward in the section, but the change is not in accordance with an exact law, for it is true only of seams far apart, not of those near together. Similar variation is observed in a seam, when followed for a considerable distance. The roof in each case has its own plants along with others not peculiar to it. The exposed section in southern Dourges is about 750 meters thick with 80 coal seams, measuring from one centimeter to a meter and a half. The area is greatly disturbed by folds and faults.

There are 36 beds of sandstone, the thickest being 22 meters. They vary greatly but not abruptly and consist of quartz grains with clay and some mica. Occasionally, they contain pockets of bright coal, and trunks of trees are not rare. Sandstone, at times, replaces a coal bed, though the mur and toit persist in such cases. Shale in roof of a coal seam is darkest near the coal but the best impressions of plants are at about a half meter above. He notes one marine deposit, about 7 meters thick, containing many specimens of *Productus* and *Orthoceras*.

Breton groups the coals into grasses, which ignite readily, are rich in gas, fuse well, give off dense smoke and leave a white ash, and sèches, less easily ignited, burn slowly, give less smoke, do not agglutinate and leave a reddish ash. These often have much mineral charcoal, which bears close resemblance to wood charcoal. Coal seams usually have shale at top or bottom or as partings, which, in the fat coals, is combustible and is used as fuel for the boilers or is given to the poor. He emphasizes the fact that, very often, there is a veinette near a thick seam, with which it is apt to unite.

He groups the deposits into faisceaux. The highest is that of the charbons tres-gras, shown in the eastern part of the Concession. This, about 300 meters thick, has 7 workable seams with 6.15 meters

[70] L. Breton, " Étude géologique du suá de la concession de Dourges," *Soc. des Sci. Lille,* 1872, pp. 355–422.

of coal; 10 which may be utilized when the thicker ones have been exhausted, and 8 which are too thin ever to be mined. The highest seam is the Ste.-Barbe, with maximum of a meter and a half, which is double—a characteristic of the thicker seams. Veine 9, long mined at one colliery, is of uncertain value, for within a few meters it may change in thickness from 3 or 4 meters to a petty veinette. It is always in a single bench and has a faux-toit. The coal is very clean and much prized for manufacture of illuminating·gas, though it has little lump. The thickest seam is the Veine a trois sillons, with 0.60, 0.40, 0.40 of coal and 0.30 of bituminous shale in two partings; it yields 60 per cent. of lump coal.

The faisceau de charbons gras, 190 meters thick, has 5 workable seams with 3.50 meters of coal. The seams are irregular and some of them are merely local; one, a meter thick at the west and yielding excellent lump coal, becomes poor toward the east and at length is replaced with sandstone. In its roof are vertical *Calamites,* of which the roots are in the coal. The demi-gras faisceau has five thin but workable seams, one of which has *Stigmaria* in the roof.

Coals from the highest faisceau have 28 to 32 per cent. of volatile, those of the middle have 25 to 28, and those of the lowest have 22 to 25. Breton asserts seams cannot be identified or their position determined by means of composition.

Rock Fragments in Coal.—The presence of rock fragments in coal seams has been observed by Stainier and Schmitz in Belgium and by Barrios in France.

Stainier[71] found rolled pebbles in the 500-meter level of a seam near Charleroi, where they are not uncommon; but none has been found in the 250-meter level. They are rounded and have a coaly covering. The dimensions of two of them are 0.07 by 0.045 by 0.10 and 0.14 by 0.08 by 0.16 meter. These are quartzitic sandstone. A similar pebble from a seam in the Huy district is 0.15 by 0.10 by 0.04, rudely triangular and the edges are rounded. Schmitz obtained from the Veine Leopold near Charleroi sandstone pebbles, perfectly rounded and covered with a crust of coal. Stainier saw large, rounded pebbles in the Grande Veine at Gosselius. They are pres-

[71] X. Stainier, " On the Pebbles found in Belgian Coal Seams," *Trans. Manch. Geol. Soc.,* Vol. XXXIV., 1896, Sep., pp. 1–19.

ent in the Grande Veine of Centre, that of Charleroi, Dix-Paumes, Gros Pierre, Caillette and other seams. Some have been discovered in partings, in the roof and in the mur. The largest weighs 25 kilogrammes and most of them are sandstone. Stainier thinks that these pebbles must have been entangled in roots of trees, floated into the sea.

Schmitz[72] asserts that rolled pebbles are not so rare as some writers have supposed; they are not exceptional but are of common occurrence throughout the coal formation. He thinks that they confirm sympathy for the French doctrine, which assumes that the plant materials were changed into coal before burial in deltas. He suggests that, on the shores of coal lagoons, movements of water more or less rapid had brought fragments of rock with the vegetable alluvium; a long voyage in the *bouillie vegetale* would bring about the coating of coal.

Barrois's[73] exhaustive study was based upon a collection of more than 300 pebbles made in the Veine-du-Nord at mines of the Compagnie d'Aniche. The seam is regular and, though thin, 0.45 to 0.60 meter, it has been mined profitably for a long time. The coal is of excellent quality, demi-gras, with 13 per cent. of volatile and comparatively little ash. The mur has abundance of rootlets and at half a meter below the coal there are many large rhizomes of *Stigmaria* with appendages. The roof is fine shale, without animal fossils, has no erect stems but has impressions of *Lepidodendron* and Calamites. The faux-toit is shale and coal, never more than a half meter thick.

The pebbles vary greatly in shape and are distributed irregularly in the coal from mur to toit. Their position indicates that they were not brought in by currents and some have salient angles, which would have been destroyed by even gentle rubbing. The crust is coal, laminated and brilliant, often with pyrite, derived from the coal. It is adherent, is removed only with difficulty and contains more volatile than is found in the surrounding coal.

[72] G. Schmitz, " A propos des cailloux roulés du houiller," *Ann. Soc. Geol. Belg.,* t. XXI., 1894, Bull., pp. lxxi–lxxv.

[73] C. Barrois, " Galets trouvés dans le charbon d'Aniche (Nord)," *Ann. Soc. Geol. du Nord,* t. 36, 1907, pp. 248–330.

The pebbles differ in character. Some are of feldspathic sandstone, the feldspar being completely decomposed. These, at times, contain fragments of Coal Measures plants. Others are quartzites of types belonging to the Coal Measures; but there are some which appear to be of Cambro-Silurian origin, though without fossils and some are of gneiss. Eighty-six per cent. are from the Coal Measures, 2 from Cambro-Silurian and 12 are from the Archean. The Carboniferous specimens are from the Flines (Andenne) and Chokier assises (Namurien of Stainier). The forms vary; subangular, 63 per cent., and rolled, 37. The weights are 1 gramme to 1 kilogramme, 73 per cent.; 1 to 10 kilogrammes, 24 per cent.; and still heavier, 3 per cent. The largest are of sandstone.

There must have been land where coal rocks and those of earlier age were exposed. The area of outcropping coal rocks must have been extensive and near at hand, as is evident from shape of the specimens. These were from the north side of the trough, where the rocks had become hard before tectonic disturbance occurred. All efforts to explain their presence as due to torrential action must be abandoned. The pebbles had been exposed for a long time; some were wasted by rubbing, others seem to have been worn by moving strata or by wind action; but all evidence shows that they endured long alteration in free air.

Erect Stems—Stainier[74] has described erect trunks observed by him at two localities. At the Falisole colliery, the Veine Lambiotte rests on a sandstone, containing a veinette, which occasionally unites with the main seam. At usually 4 but occasionally 12 meters above the coal is a veinette, which at one locality unites with it. In this interval numerous trunks were seen, but they are without roots and all features indicate that they are merely "snags." At the other locality, the trunks are cut off by faulting, but the evidence presented by Stainier does not suggest that the stems are *in loco natali*. The seam at this place shows signs of erosion during deposition of the overlying sandstone. Smeysters[75] has described the mode of occur-

[74] X. Stainier, "Un gisement de troncs d' arbres débout au Charbonnage de Falisole," *Bull. Soc. Belg. de Geol.,* t. XVII., 1902, Mem., pp. 69–76. The same, 1903, pp. 539–544.

[75] J. Smeysters, "Note sur les troncs d'arbres fossiles," *Ann. Mines de Belgique,* t. X., 1905, pp. 1–12.

rence of several vertical stems in a mine near Charleroi; but these seem to be transported fragments; there is no reason for supposing that they are *sur place*.

Schmitz[76] in 1895 found 33 stumps of erect trees in the roof of the Grande Veine at Grand Bac in the Liége district, where the coal seam is vertical. The glossy, brilliant basal surface of the roof is exposed in the wall throughout and observers could determine the circular markings, indicating bases of the trunks. In almost every case, the cylinders of these petrified trees retained the bark, coalified, sometimes a centimeter thick, under which were leaf scars showing that they are *Sigillaria*. As the stems are vertical to the stratification, detailed study of their surface was impossible. The exposure is on the north wall of the gallery, 2 by 93 meters, giving to each stem a space of 5.60 square meters, a condition favoring belief that they are *in loco natali*. But the stems are distinctly cut off sharply at approach to the coal. Most of them show the swelling which belongs near the roots, but no trace of roots appears. It is clear that the rooting of these trees could not be in the toit, for that is merely a few centimeters of carbonaceous shale. This thin toit contains many impressions of plants and stalks of lycopods and equisetaceæ, all lying flat. Four of these were seen passing across the base of a trunk, which proves that the stems are not *in loco natali*.

But the whole condition indicates rather that the overlying rock, penetrated by the trunks, has slipped on the coal during the disturbance. This polished the surface at the plane of contact and cut off the stems as sharply as though they had been sawed. Schmitz, in a later article, recognized this condition and regarded the forest as *in loco natali*. Long ago, Breton,[77] in his description of the Concession of Dourges, stated that, in some mines, *Calamites* were found normal to the bed, in the place where they grew. The roots often rest on the coal and the stems traverse the roof. In the pit, Ste.-Hermite, one can see in a gallery, 60 meters long, a number of *Calamites,* resting by their thin part on the coal, the stems penetrating the over-

[76] G. Schmitz, "Un banc à troncs débout," etc., *Bull. Acad. Roy. de Belg.,* III., t. XXXI., 1896, pp. 260–266. "Formation sur place de houille," *Rev. des Quest, Scient.,* April, 1906, p. 31.

[77] L. Breton, op, cit., pp. 383, 389.

lying shale, 3 meters thick. Sandstone overlies the shale and it fills the *Calamites* to their roots, which are in the coal. *Sigillariæ* are sometimes vertical to the stratification. *Stigmaria* characterizes the mur and sometimes is found in the roof.

Boulay[78] states that in the roof of mine Veine Christiane within the Concession of Bully-Grenay, in Pas-de-Calais, he saw great erect trunks of *Sigillaria,* 30 to 60 centimeters in diameter. The species was not determinable, but the roots are unquestionably *Stigmaria abbreviata.* This seam is higher in the section than the Ste.-Barbe of Dourges. Bertrand[79] examined two erect stems in a mine within the Lens Concession of Pas-de-Calais. One, in roof of the Veine Désiré and not absolutely vertical, has its base resting on a coaly film; underneath the veinule is abundance of *Stigmaria* rootlets and a great *Stigmaria* rhizome was seen; but this could not be traced as a slip had occurred at the horizon of the veinule, so that no proof could be obtained that this *Lepidodendron* stump is in its original place. The other stump, a *Sigillaria,* was in roof of a seam, 14 meters above Désiré; the broadened base rests directly on the seam and its roots cannot be traced; if it be *in situ,* the roots would be unrecognizable, as they wiuld have been changed into coal. The stump directly above Désiré is cut off at base as though sawed. This is a common condition, observed in other coal areas.

Barrois[80] discussed the matter generally in connection with description of vertical stems at many horizons in the Lens and Liévin Concessions within Pas-de-Calais. The existence of such trees had been known for a long time and they had been regarded usually as being in the place of growth; but latterly some geologists have maintained that they had been transported, A recent discovery of erect trees in the roof of the Veine Leonard of Liévin seems to confirm the later explanation. He presents a diagram, drawn carefully to a scale, which shows the relations. The trees are parallel, are envel-

[77] L'Abbe Boulay, "Recherches de palaeontologie végétale," etc., *Soc. Scient. Bruxelles,* 4me année, 1880, p. 32.

[79] P. Bertrand, "Note sur des arbres, débout à la fosse No. 3 des mines de Noeux," *Ann. Soc. Geol. Nord,* t. 37, 1908, pp. 50,51.

[80] C. Barrios, "Note sur la repartition des arbres débout dans le terrain houiller de Lens et de Liévin," *Ann. Soc. Geol. du Nord,* t. 40, 1911, pp. 187–196.

oped' in shale, with roots at the lower end, which do not penetrate the coal; at least, if they do, they have been converted into coal and become unrecognizable.

During a number of years, Barrois, P. Bertrand and some other geologists had studied the roofs of coal beds and they succeeded in classifying them into (1) roofs of sandstone, the grains varying in coarseness, containing much vegetable débris, but leaves have disappeared; (2) roofs of shale, carbonaceous, with plants, the leaves in fine condition, showing that they had not been transported far and that the deposition had been made in quiet, shallow water; (3) roofs of bituminous shale, black, ampelitic, and with fish remains; always very thin; the deposit was made slowly and the water was not free from mud; (4) roofs of bituminous shale, brown, contains lamellibranchs of deep- and brackish-water types; these also were formed slowly and the water was not deep or agitated violently; (5) roofs of calcareous shale with marine shells; the water was deeper and liable to greater movements.

If the trees had been floated in, they should occur in roofs of deep water origin, they should not be in roofs, formed in water so shallow that they could not be introduced in vertical position. But they are present in shallow water roofs. At Liévin, they have been obtained from 19 veines or passees (veinules) with typical shallow water roofs and from 7 roofs of intermediate types. Distinctly deep water roofs are not wanting, there being 28 of them, not one of which contains erect trees. Barrois regards the evidence as sustaining the assertion of *in situ* origin for the stems.

The Central Plateau of France.—The coal basins of central France, about 300 in number, are in large part of little more than local importance; but some of them are extremely important because the seams attain great thickness and yield a high-grade fuel. All are of limnic origin and the Coal Measures deposits belong mostly to the Stephanien. The general features are much the same in all, so that it is necessary to refer only to the basins with which all are familiar.

The Coal basin of the *Loire* or of *St. Étienne* was studied by Gruner, whose report was published in 1882 and by Grand'Eury,[81]

[81] L. Gruner, Bassin houiller de la Loire," Paris, 1882, pp. 168–173, 204–237, 483–486; C. Grand 'Eury, " Bassin de la Loire," *C. R. Cong. Int. Geol.*, Paris, 1900, pp. 521–543, *Livret-Guide des Excursions,"* XIb., 1900.

whose results, chiefly from the paleobotanist's standpoint, were presented in many memoirs. Two papers, published by the International Geological Congress, may be accepted as summarizing his conclusions.

According to Gruner, the succession, ascending is:

Brêche de la base; Étage houiller de Rive-de-Gier; Étage sterile de St. Chamond; Étage houiller inférieur de St.-Étienne; Étage moyen de St.-Étienne; Étage supérieur de St.-Étienne; Étage sterile, or Permo-Carboniferous of Grand'Eury.

These outcrop in concentric curves, now broken and distorted by faults. The basin embraces about 80 square miles; the second and third stages occupy not far from nine tenths of the area, if they exist under the higher divisions; the fourth is present in almost one half of the basin; the fifth, in less than one fourth, while the sixth and seventh are in less than one twelfth.

The Brêche is a confused mass of angular fragments, slides from primitive rocks, surrounding the basin, and nature of the fragments differs according to locality, granite prevailing at some, gneiss at others. It is from 20 to 200 meters thick and the top is at 15 to 20 meters below the lowest coal seam.

The Rive-de-Gier, consisting of sandstone with some shale, is 100 to 120 meters thick and has four workable coal seams, as well as several thin streaks. The highest, Grand Masse, is divided by a parting of white sand, known as Nerf blanc and not more than 10 inches thick. Coal from the lower bench is hard, dull, contains much oxygen, is good fuel for grates and is termed " rafford "; that from the upper bench, termed " maréchal," is tender, brilliant, has less oxygen than the other and is excellent for gas and coke. In the western part of the area, coal from both benches has less volatile than at the east and, in the last concessions, it becomes anthracitic at depth of 500 to 600 meters. At the eastern limit of the Rive-de-Gier, the Grand Masse is from 0 to 0.50 meter thick; but it increases toward the west and becomes 15 meters at Grand'Croix. It thins away at the borders of the area. The roof is sandstone; during its deposition, the coal suffered much from erosion, all having been removed at numerous places; the mur is tender, often swells and replaces much of the coal. The seam, les Batardes, 35 meters lower,

is double with a parting, o to 8 meters thick.   The coal thickens and improves in quality toward the west, becoming 5 meters near Grand-'Croix, where the benches are united.   The roof of the upper bench is sandstone and erosion of the coal is frequent; but that of the lower bench is shale and the coal is always regular.   Two lower seams have poor coal; one has maximum thickness of 1.40 meter near Grand'Croix, but the other is a lens, disappearing in all directions.

Beyond the Rive-de-Gier, one reaches the sterile stage of St.-Chamond, 500 to 800 meters thick, the lower portion a coarse conglomerate, the upper less coarse and micaceous.   The upper or micaceous division is thin at southeastern localities but it increases at expense of the lower portion until, near St.-Chamond, it has replaced it almost wholly.   Thin coal seams occur in the area of coarse deposits but they disappear when the micaceous beds predominate.

The Étage de St.-Étienne inférieur, 850 to 950 meters thick, has 10 to 12 coal seams, some of which occasionally divide.   They vary abruptly in thickness as well as in quality of the coal.   Seams 8 and 12 at times yield excellent coking coal but at others they are so dirty as to be worthless.   Coal seams are regular where the rocks are quartzo-feldspathic but become worthless or disappear when the rocks are micaceous.   The upper division has one important seam, o to 6 meters thick, which suffered much from contemporaneous erosion, having been removed wholly in many places.   The coal is good for coke, though it must be washed to remove the high ash.   The coal of this stage was formed of *Cordaites, Psaroniocaulon, Aulacopteris* and *Calamites.*

The Middle stage of St.-Étienne, about 350 meters thick, has 8 or 9 coal seams separable into two divisions; the lower has two seams.   In the upper, Nos. 1 and 2 have inferior coal containing kidneys of iron ore and trunks of trees, replaced with carbonate of iron.   Ordinarily they are not mined, but No. 2 occasionally becomes 3 meters thick and has good coal.   Nos. 2 and 3 are united at many places; the latter averages 4 to 5 meters; No. 4 is ordinarily at 20 meters below 3, but the interval varies from o to 24 meters.   At times, No. 3 is 10 and 12 meters thick, but in such cases it consists of 1, 2, 3 and 4 united.   The coal of this stage originated from the same plants as in the Lower St.-Étienne.

The Étage supérieur de St.-Étienne, 250 to 350 meters thick, is in an area of 1,000 to 1,500 meters wide by 11 kilometers long. It has 10 or 12 coal seams with total extreme thickness of 15 to 20 meters at the east but diminishing rapidly toward the west, where micaceous shales prevail. The lowest seams are of moderate thickness and yield inferior coal. The seams in the middle are 2.50 to 7 meters and are good. The highest seam, 3 to 10 meters, yields friable coal. In all cases the coal is rich in volatile and appears to be composed of *Psaroniocaulon, Stipitopteris* and *Calamites*.

The upper sterile stage or Permo-Carboniferous, apparently not more than 475 meters thick, consists of shaly green and red sandstone. The passage from St.-Étienne is gradual and, as far as can be gathered from Gruner's statements, the succession is conformable.

Gruner notes that the forests of this basin are confined to the Middle St.-Étienne. Long ago, the upper one was described by Alex. Brongniart.[82] Though are rocks are horizontal, they have suffered from a slight movement, which has broken the continuity of many stems, so that the root portion has been shifted. Eighteen vertical stems are shown on the plate, which represents about 75 feet of the wall, and roots are distinct on many of them. Brongniart was confident that this is part of a forest of bamboo-like plants. The interior of the stems is filled with sandstone like that in which they occur; but this is coated by coaly or ferruginous material.

Gruner says that another forest is at 100 meters lower in the section. He saw in the Treuil mine 12 trunks in a space 12 meters square. These rest directly on the coal, which is not penetrated by the roots, though in some cases they spread out upon it. These are *Sigillaria*. Similar conditions were observed elsewhere. The relations in the mur are different from those observed in the roof, for at St.-Étienne he saw rootlets descending from the coal into the underclay. This condition is especially clear in les Batardes of the Rive-de-Gier, where *Stigmaria* abound in the mur. His discussions on pp. 168–173 and 483–496 should be consulted by all who are interested in the matter.

[82] Alex. Brongniart, " The Fossil Vegetables Traversing the Beds of the Coal Measures," *Ann. des Mines,* 1821; translated in de la Beche's " Selection of Geological Memoirs," etc., London, 1836, pp. 208–216.

Grand'Eury presented to the Geological Congress a paper in which he discussed elaborately the occurrence of various types of plants. He regards the deposits as Stephanien. The paper in the Guide gives more of detail respecting localization.

The Upper Sterile stage passes upward into coarse conglomerate, which Stur thought analogous to the Rothliegende of Rossitz; but there is no unconformity. The Rothliegende flora is not abundant. *Cordaites* and *Pecopteris* are present and *Tæniopteris abnormis* has been found but no trace of *Callipteris* has been observed. *Walchia pinniformis* was seen in the St.-Chamond, but it does not continue into the St.-Étienne stages. The Avaize (Middle St.-Étienne) contains precursors of the Permian.

The Productive Coal Measures show erect trees with their roots, associated with well-preserved plant impressions, all indicating autochthonous vegetation. Rooted trunks and stumps are uncovered daily near St.-Étienne. His belief is that the trees, in every case, grew in water with their roots penetrating the ground below. In many cases, the stems have been removed during mining work but usually the vegetable soil was not disturbed; it is traversed by roots, some herbaceous, some ligneous, which often pierce impressions of leaves. *Stigmaria* is the most common form. These have their roots spread out in normal position and frequently retain the delicate appendages. They penetrate the underclay and are interlaced in it. There are many other types, which he regards as even more satisfactory. Chief among these is *Calamites,* whose erect stems give off rhizomes, which, in turn, give off rootlets; all of the subterranean organs are well preserved and are in normal position. *Calamodendrons* have their stems bound to the soil by a complete system of roots. *Psaronius* stems are very numerous and are surrounded at base by innumerable roots, pushed down obliquely into the soil. When the plant, subjected to accumulation of alluvium, was obliged, in order to live, to give off free roots in the water, these passed downward and buried themselves in the soil below. Stumps of *Cordaites* are equally numerous with their woody roots, divided and subdivided even to rootlets, which have a comb-like arrangement. *Syringodendrons,* with complete *Stigmaria* roots and rootlets are of frequent occurrence. Fossil fruits are abundant. Roots of

stumps are involved in a maze and he has observed cases where the roots of one stump penetrate stumps at a lower horizon. Some long roots cross several layers of subjacent rock. He is convinced that the fossil forests were developed *sur place*.

Commentry.—The petty basin of Commentry, though embracing barely six square miles, is perhaps more familiar to geologists than is any other of the Plateau basins, St.-Étienne alone excepted. It was studied during many years by Fayol,[83] who described it in an elaborate memoir and utilized the results as basis for his well-known Delta hypothesis. This memoir is so detailed and contains so much of interest that it is difficult to prepare a synopsis of the facts bearing on matters concerned in this study.

The basin is a depression in Archean and apparently contains no rocks older than the higher Carboniferous. It is divided into five strips, extending from north to south: Bourdesoulles, at west, containing coarse rocks; Le Marais-les Ferriéres, sandstones, shales and coal seams; Montassiègè sandstones and blocks of rock; Les Pegauds, sandstone, conglomerates, shale and coal seams; Longeroux, at east side, conglomerates. Montassiègè separates the sub-basins of Les Ferriéres and les Pegauds, which together make up barely one third of the whole area and in each case have only a very small space occupied by coal. The coarser rocks predominate throughout, shale and coal being only 4.5 per cent. of the whole mass.

The important coal deposit of les Pegauds has an outcrop rudely resembling the capital letter C. At the easterly extremity, it begins as a single seam of insignificant thickness, but increases along the curved outcrop, dividing and at last thinning away to disappearance on the east side of Montassiègè, where it is represented by 8 thin seams within a vertical section of 200 meters. Southwardly within the curve, it dips at 0 to 50 degrees and finally comes to an end at a depth of 350 meters. Near Longeroux, at the east, the thickness is only a few centimeters, but at the northerly part of the outcrop, the main portion, known as the Grande Couche, averages between 10 and 12 meters for a distance of 2.5 kilometers. Thence westwardly it decreases to disappearance. The coal for the most part is caking and

[83] H. Fayol, " Études sur le terrain houiller de Commentry," Liv. prem. St.-Étienne, 1887.

with long flame, but it varies greatly. One finds it passing from coal to cannel, boghead, bituminous shale and even to sandstone or conglomerate. Sometimes it is clean from floor to roof, 15 or 20 meters; at others, it is divided by intercalated shale, sandstone or conglomerate, up to several meters thick. This great mass of coal is at 500 to 800 meters above the base of the formation, near which are some irregular deposits of anthracite.

The conditions are similar in les Ferriéres, where the principal deposit, apparently contemporaneous with that of les Pegauds, has a curved outcrop and thins to disappearance at both extremities. The coal has less volatile than that in the other sub-basin.

Fine sandstone prevails in les Pegauds, but coarse material is not wanting. One remarkable mass, marking the course of a violent flood, was formed shortly before the beginning of the Grande Couche. It is coarsest midway, where some blocks are of enormous size, but it shades away on each side into fine sand. Another coarse deposit is intercalated in the Grande Couche, but it is only a few hundred meters long and passes into the coal at each extremity of its outcrop. Fragments of Coal Measures rocks are found in all parts of the section. Those of shale, by their form, suggest to Fayol that they were plastic when enclosed. The pebbles of coal usually resemble in composition the coal nearest to them; those of the basal portion are anthracitic; those of les Ferriéres are maigre but in deposits overlying the Grande Couche the pebbles are usually of coal with long flame, though rare specimens of anthracite occur.

The coal occurs in films and in seams. *Calamites* are rare in the roof of Grande Couche but *Calamodendron* abounds. The flora is the same throughout and continues into the Permian; but there is distinct localization of forms. *Lepidodendron* and *Stigmaria* are present in the southwestern portion but are wanting in the eastern. *Knorria, Lepidophloios, Lepidostrobus* are in the roof at western localities. Fish and insect remains are abundant in some portions. Renault studied many specimens of trunks and branches enclosed in the fine sands. Their coal is derived from decomposition of vegetable material; there is no evidence of enrichment by infiltration, as the enclosing sand contains neither coal nor bitumen. At times a

branch is found, which has been changed in one portion into clean, compact coal, while in the other it has become fusain.

Aside from shaly seams, the coal usually has from 6 to 8 per cent. of ash, yields 60 to 62 per cent. of bright coke and gives off gas burning with brilliant flame. Analyses by Regnault and by Carnot give the ultimate composition:

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
I.........	82.92	5.30	11.78
II.........	83.21	5.57	11.22

Cannel is of common occurrence in the Grande Couche as thin streaks or as lenses, which sometimes extend hundreds of meters; it yields a brilliant gas and has from 33 to 58 per cent. of carbon. Fayol seems to be inclined to believe that difference in character of coal may be related in some way to the ash-content; ordinary coal has 5 to 10, cannel, 7 to 12 and boghead 25 to 50 per cent. of ash.

Trunks, branches, etc., are in rocks of all kinds; are usually prostrate, but some are inclined, others erect. There are few in conglomerates, ten times as many in sandstones, 200 times as many in shales and 1,000 times as many in coal. Erect stems are rare in coal and shale, proportionately they are most numerous in the coarser rocks. At one locality, Fayol found a fern stem inverted. Attached branches are rare but many stems retain their roots. Still, the most of them have neither roots nor branches; but there are stumps retaining roots spread out on the underlying deposit, which they do not penetrate. One such stump, with diameter of one meter, showed 15 *Stigmariæ* radiating from it and enclosing a space of about 400 square feet. These *Stigmariæ* are arranged regularly and are flattened. Stems of trees, numerous in the coal, are compressed, the interior portions having disappeared, the rind only remaining, converted into coal.

The roof is of ordinary carbonaceous or bituminous shale, passing upward gradually into sandstone. Commonly it is rich in plant remains. The floor is usually carbonaceous shale, but occasionally sandstone, and the passage to the coal is gradual. There are many cases of contemporaneous erosion. One in the Tranchée de Forêt

removed the roof and much of the coal along a line of 80 meters on the outcrop. About 40 meters of Permian beds remain; the succession is discordant.

Fayol's conception is that the coals were deposited as transported vegetable matter on the sides of the submerged deltas in the lake or in the bays separating them. A remarkable feature observed in the Tranchée de l'Esperance is regarded by him as due to a slide on the watersoaked surface of the delta. The folding is very distinct in a close synclinal where the rocks are different in color from those of the wrinkled Coal Measures beds on one side, where exposures are complete. As the coal has been mined in vast open works, the conditions are well shown in two adjacent excavations. The locality was visited by Stevenson[84] in 1909, who explained the matter very differently. He regarded the light colored rocks of the synclinal as a deposit filling a channel-way eroded after the coal had been consolidated. The distortion of the strata was caused by eruption of a great mass of dioritine, the lateral thrust folding the rocks, crushing the coal into polished lenses and causing shale beds between sandstones to become wrinkled. This thrust produced a horizontal fault under the severely flexed rocks, which is well-exposed in the Tranchées Longeroux and de l'Esperance. The disturbance becomes insignificant east from the former tranchée as distance from the dioritine increases.

Autun.—Permian in the little basin of Autun contains the boghead, which, according to the studies by Bertrand and Renault,[85] consists chiefly of algæ enclosed in a " fundamental matter." It closely resembles the Kerosene Shale of New South Wales.

The deposit is thin and in limited space; it extends north from Autun for about 7 kilometers and is from 150 to 450 meters wide. It disappears away from a certain depth and is represented on the borders only by small lentils, irregularly scattered. The principal lens is from 23 to 25 centimeters thick, but exploitation is profitable as the yield of oil on distillation is very large. The boghead is

[84] J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sciences,* Vol. XIX., 1910, p. 198.

[85] C.-Eg. Bertrand et B. Renault, " Pila bibractensis et le boghead d'Autun," *Bull. Soc. d'Hist. Nat. d'Autun,* t. 15, 1892. sep., pp. 1–93.

homogeneous, elastic, broken with difficulty, is deep brown and has a resinous luster. The lamination, due to colonies of algæ, is often minute and recognizable only on close examination. The "fundamental matter" contains infiltrations, pyrite, calcite and thelotite, the last being an enriching material, coloring the algæ blood-red. Analyses of specimens from two localities show

	Volatile.	Ash.
Margenne	65.6	34.4
Thelots	73.75	26.25

but these were selected specimens; ordinarily the ash varies from 35 to 48 per cent. The organic matter consists of carbon, 80; hydrogen, 10; oxygen and nitrogen, 10; the ash from the two localities named contains

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Margenne	67.7	10.8	15.7
Thelots	60.5	14.4	17.4

The algæ, *Pila bibractensis,* B. and R., belong to the gelatinous group and are fresh-water forms like the fleurs d'eau. No spores, sporangia, sexual organs or embryos have been discovered. These algæ, at times, compose 75.5 per cent. of the whole mass. The "fundamental matter" contains remains of organisms, *Pila,* fish and grains of pollen; the last being in great abundance, 25,000 to 80,000 in a cubic centimeter, indicating showers of pollen. Besides these, are fragments of wood and leaves; but neither cyprids nor diatoms were observed.

The deposit is a lens, formed as cannel in a pond as is the organic mud, which so often is foundation for a peat deposit. The reasons for regarding the thelotite, pyrite and calcite as infiltrates are not very clear. Certainly the source of the thelotite was not ascertained. If it came from the enclosing bituminous shale, it can hardly be regarded as extraneous. Bertrand and Renault think that the boghead was formed in quiet water with little or no current and they regard the fundamental matter as ulmin which was held in solution. It is quite possible that the lime, present in considerable proportion, would suffice to precipitate the ulmin, but in that case it

is difficult to conceive how the supply could be maintained in quiet water. It must be remembered that the proportion of dissolved ulmin is very small: Smith[86] ascertained that very brown water contains only 4 grains to the gallon, and that if the quantity be 6 grains, the color is intensely dark.

It should be noted here that the conclusions reached by Bertrand and Renault have been controverted emphatically by Jeffrey and by Thiessen,[87] who employed improved methods of preparing the material. Jeffrey examined the Autun and other Bogheads and found no algæ but abundance of spores. Thiessen's results were very similar.

Bretagne.—Several small basins have escaped erosion in the area of the lower Loire Riven within Brittany. A general description of them was published by Barrois about 25 years ago, but his work is not now within the writer's reach. The only available notes are by Rolland,[88] presented many years since. These coals, almost anthracite, are regarded now as belonging to the Culm. The deposits described by Rolland are said to extend from Doué in Maine-et-Loire to Nort in Loire-Inférieure, about 40 leagues. He divides the section into eight systems, each with a conglomerate at base, the intervening rocks being sandstones and blackish shales. The first five systems, in each case, contain only thin streaks of coal, but the sixth, Goismard, has two seams, Petit and Grand Goismard, which at times unite and are mined. The upper, Petit, averaging about 50 centimeters, yields a hard lump coal and has as its roof a sandstone, pierre carrée, almost 70 meters thick. Its faux-toit is fine-grained sand, without cement and about one meter thick; it passes downward into a loose material, termed "tourte" by the miners and consisting mostly of decomposed feldspar. The mur of this seam, roof of the Grand seam, is shaly sandstone, 6 to 8 meters thick at the outcrop; at 100 meters down the dip, it is 3 and at 200 it is only 1 meter. In the deepest portion of the works, the seams have

[86] R. Angus Smith, *Manch. Lit. Phil. Soc.,* III., Vol. IV., 1871, pp. 50, 63.

[87] E. C. Jeffrey, "On the Nature of Some Supposed Algal Coals," *Proc. Amer. Acad. Sci.,* Vol. XLVI., 1910, pp. 273–390; R. Thiessen, "Plant Remains Composing Coal," *Science,* N. S., Vol. XXXIII., 1911, pp. 537–552.

[88] M. Rolland, "Notice sur le terrain anthraxifére des bords de la Loire," etc., *Bull. Soc. Geol. France,* t. XII., p. 463.

united and at a short distance beyond the union they disappear. The lower seam, 60 centimeters thick, yields a friable coal. Its mur is a tender shale, which breaks down into a whitish clay. The seventh system has three non-persistent seams and the eighth has but one; these are all thin.

Some sandstones in the fourth have many impressions of *Calamites* and the conglomerate at base contains many large, flattened fragments of stems. Those of the fifth have great abundance of *Calamites*, as well as of trunks of "palms," which are vertical to the stratification and are replaced with sandstone. Occasionally the shales in this system as well as those associated with coal in the eighth, contain impressions of leaves.

The coal is maigre with not more than 13 per cent. of volatile.

Spain.

Barrois[89] devotes 82 pages of his work on the northwestern part of Spain to the Carboniferous of the Asturias. He recognizes three assises: *Assise de Leña,* consisting of sandstones, conglomerate, shales, marine limestones and thin layers of coals; this he regards as equivalent to the Culm of Lower Carboniferous. *Assise de Sama,* equivalent to the terrain houiller moyen of Nord, France, as determined by Grand'Eury and Zeiller after study of the plants. The rocks are sandstones, some persistent conglomerates, rare limestones and numerous seams of coal. *Assise de Tineo,* equivalent to the terrain houiller supérieur of France, composed of shales, sandstones, some conglomerates with pebbles of Coal Measures rocks, and a large number of coal seams. There are no marine limestones. This is not conformable to the preceding deposits and in some areas it rests on the older formations.

Whether or not any representative of Permian exists in the region is uncertain. An earlier student was inclined to assign certain deposits to it, but Barrois thinks that, most probably, they belong to the Lower Carboniferous. The region has been subjected to violent disturbance, faults and overturned anticlines are numerous, so

[89] C. Barrois, " Recherches sur les terrains anciens des Asturies et de la Galice," *Mem. Soc. Geol. Nord, Lille,* 1882, t. 2, No. 1. Citations are from pages 519–600.

that detailed study is not possible in a considerable part of the area. The Coal Measures have an area of about 540 square kilometers in the Asturias and the principal basin is the Central, or Sama de Longres, containing not less than one third of the whole coal area; other basins are smaller, but in some cases are economically important.

The Assise de Leña receives its name from Pola de Leña, north from the Cantabrian Mountains, where the succession is well shown. It is exposed by an anticline in the Central basin, where its character is distinct. Near the montée de Cardeo in that basin, is a conglomerate belonging to this assise, which has aroused much discussion. It consists of large quartz pebbles, grayish white, which are marked in such manner that each observer has felt compelled to offer some explanation; some have regarded the phenomenon as due to chemical action, others think it due to pressure, to heat, etc. Barrois would explain it as due to wind agency. The sandblast produced by winds has had marked effect on quaternary pebbles in the Rhone Valley. Similar blasts could have polished or striated the pebbles of this conglomerate as they lay exposed on a beach. The coal seams of this assise are without economic value.

The Assise de Sama or lower division of the terrain houiller riche of former observers, is the important group of deposits in the Central basin. Coal seams are shown in one section associated with shales and sandstones containing impressions of *Calamites* and *Stigmaria* with nodules of clay ironstone; the coals rest on soft sandstone or shale filled with *Stigmaria*. Near Padrun is a conglomerate containing pebbles of coal, 4 to 5 centimeters in diameter. On Rio Caudal there appear to be about 30 seams of coal, arranged in groups which are separated by barren intervals. The mur usually is a compact shale crowded with *Stigmaria* and fragments of plants, but the toit has abundant beautiful impressions. A faux- toit, 10 to 15 centimeters thick, consisting of shale and coal, often covers the coal and at times is pulverulent. Barrois determined that the number of coal seams reported by earlier observers is far too great and that those who reported 72 to 80 seams failed to recognize several folds; he intimates that most probably the number is too great by at least one half. Throughout this basin, seams show much

variation in thickness, some, at times, thinning away to disappearance. One seam attains 3 meters; in one case coal only 30 centimeters thick is mined. Coals of the same age are in the small Santo-Firme basin, where the formation, resting on the Devonian, is about 500 meters thick and contains 10 coal seams. It underlies post-Carboniferous rocks. The coals show the usual tendency to vary in thickness, sometimes thinning away only to reappear within a short distance. A marine shale, rich in fossils, is roof of a coal seam in upper part of this assise.

The Assise de Tineo is confined to some small basins in the western and to two in the northern part of the old kingdom. In Tineo basin these rocks rest on the Cambrian. In Arnao and Ferrones they rest on Devonian and, because of faults, appear to be intercalated in rocks of that age. The basins of Ferrones has but one coal seam and the overlying Devonian contains fine fossils.

The province of Oviedo had 210 mines in 1869. Studies by de Aspiroz and by Paillette proved that the composition of the coal is not the same in different basins and that it varies even in the same assise. The most of the coal is bituminous but a maigre, anthracitic coal is obtained in Viñon and Calunga basins; this, of no value, may belong to the Assise de Leña. Volatile in the Central basin, belonging to the Assise de Sama, is 30 to 45 per cent. and the ash is from .04 to 3 per cent. But these are only of selected specimens. Coals from the small northern basins have theoretical interest. These give, according to analyses by Paillette:

	Volatile.	Ash.	Fixed Carbon.
Arnao	39	20	40
	49	7	42
Ferrones....................	45	12	42
	47	2	49
Santo Firme	38	5	55
	46	8	44

The Santo Firme coal belongs to Assise de Sama, that from Arnao and Ferrones, to Assise de Tineo. The difference in volatile might be attributed to the age of the coals, Santo Firme, the older, having less volatile; but Barrois thinks that another explanation, more satisfactory, may be found in the relation of composition to strati-

graphical disturbance.   The Sama seams crop at many places where faulting and folding are marked, but in Arnao and Ferrones the disturbance is far greater; the section has been overthrust and the Carboniferous underlies Devonian.   The coals which are richest in volatile are from areas which have suffered most severely from pressure.   He notes, as bearing on the matter, that Gosselet had shown for the Nord area in France that the northern part of that region had suffered very little from disturbance while, in the southern portion, disturbance had been violent, there being at times complete inversion of the section.   Yet coals are maigre in the northwest portion, whereas in the southwest, locality of greatest disturbance, one finds the fattest coals.

Great Britain.

The boundary between Permian and the Coal Measures is not always distinct in England.   The unconformity is often small and it is difficult to determine a plane of separation, as rocks of the Upper Coal Measures closely resemble the type, which at one time was thought to be characteristic of the later period.   But in considerable areas, the case is clear, for Permian rests on upturned, eroded Coal Measures.   There appears to be good reason for believing that the system of flexures, traceable from England across France and Belgium into Prussia, originated toward end of Coal Measures deposition.

Permian deposits of Great Britain are equivalent to the Zechstein and Rothliegende of the Continent, as Murchison[90] held.   They are absent from southern England and Wales and Hull believes that that area was exposed to denudation during the Permian interval. The Zechstein (Magnesian Limestone) has escaped erosion in only petty areas but the Rothliegende, covering extensive spaces in several fields, is thoroughly well marked, consisting chiefly of red and purple marls and sandstones, with occasional conglomerates and sometimes, on top, a breccia, containing fragments of trap and Silurian rocks.   In the South Staffordshire coal field, the thickness

[90] R. I. Murchison, "Siluria," p. 347; E. Hull, "Coal-Fields of Great Britain," 4th ed., 1881, p. 524.

is estimated by Jukes[91] at from 1,000 to 3,000 feet, but the lower portion is almost beyond doubt of Coal Measures age. In other fields it is much less. Coal rarely occurs; Jukes notes a local seam, 10 inches thick and resting on fireclay. Numerous casts of *Sigillaria* were obtained from red sandstones lower in the section.

The Carboniferous deposits have been grouped into:

Upper Carboniferous. Upper Coal Measures; Middle Coal Measures or Pennant Series; Lower Coal Measures or Ganister Series; Millstone Grit.

Lower Carboniferous. Yoredale Shales, equal in part to Pendleside; Carboniferous Limestone.

Classification of the Coal Measures is perplexing and field workers have employed designations in the local sense. Kidston has offered a grouping based on an elaborate study of the plants:

Radstockian Series; Staffordian Series; Westphalian Series; Lanarkian Series.

The first two are the Upper, the third is the Middle, while the fourth includes the Lower Coal Measures and the Millstone Grit.[92]

Happily, the matters involved in this study have, except in a few cases, little to do with questions of classification, so that, in preparation of synopses of reports, it is sufficient usually to accept the grouping employed by the authors.

The South Wales Coalfield.—This, in the southern portion of England and Wales, was restudied by A. Strahan, W. Gibson, R. H. Tiddeman and T. C. Cantrill.[92] It extends from Monmouthshire at the east to Pembrokeshire at the west. The Permian is not present but the Carboniferous, Upper and Lower, is well marked. The Coal Measures are readily divisible into Upper, Pennant or Middle, and Lower, which are now regarded as equivalent to those of other fields. The Millstone Grit is persistent and characteristic; it and the Coal Measures thicken greatly toward the east; but their total

[91] J. B. Jukes, "The South Staffordshire Coal-Field," 2d. Ed., 1859, pp. 12, 13.

[92] This classification was presented first in 1888, but the final statement with explanations is given in R. Kidston, *Trans. Roy. Soc. Edinb.,* Vol. I., 1914, pp. 74, 75.

[93] "The South Wales Coal-Field," Parts I.–X., Geol. Surv. Mem., 1899–1912.

thickness is much less than was estimated by the earlier survey. The Lower Carboniferous limestones and shales are without coal.

The Upper Coal Measures, consisting of shales and sandstones with mostly irregular coal seams, has at base a well-defined persistent coal, known as Mynyddislwyn, Llanwit I, Wernffraith and Swansea in different districts. A vertical section of 111 feet in the Blackwood Valley near Newport of Monmouthshire, shows six coals, 6 to 30 inches thick, but they are extremely irregular. The Mynyddislwyn is double and the parting varies in thickness; in one area, it varies from 2 to 24 feet; in another, from 6 inches to 15 feet, while in another the parting of 2 feet becomes 15 feet within a short distance. Crossbedded sandstone is not unusual in the eastern part of the field.

The middle division or Pennant Grit is for the most part a clayey somewhat feldspathic rock at the east, which thickens very rapidly toward the west, where it is broken by shales. No workable coals are known at the east but southwardly and westwardly several seams become workable, though as a rule the coal is of inferior quality. The Tillery Coal, known in portions of the field as the Brither, Rhondda 2, Ynysarwed and Garn Swilt, is at the base. This Grit has occasional bands of conglomerate, containing quartz pebbles and rounded fragments of ironstone, coal and Coal Measures rocks. In Glamorganshire, where shales are in upper part of the Pennant, there are three workable seams, while farther west some coals are important. A crossbedded sandstone is the roof of Rhondda 2; at others that roof is conglomerate with pebbles of ironstone and coal; this is common in western localities.

The Lower or Steam Coal Series consists very largely of shale at the east but sandstone increases toward the west. It contains the coals which have made the field so important. In the upper portion, below the Tillery Coal, there occurs a notable thickness of red shale, which is very characteristic along the eastern side. The rocks generally show much variation, thickening rapidly toward the west, where they become coarser.

The coal seams change much in structure as well as in quality, but some of them are so persistent as to be definite stratigraphical horizons. The best-marked seam is that known as the Rock, Black,

Ras-Las, Nine-feet, Bydylog in different parts of the field; its varia-
tions may be taken as typical. At most localities, it is double with
a variable parting of clay, but there are definite partings, without
inorganic deposit, separating benches, differing in the character of
their coal. At some localities, it is troubled by "nips," the shale
roof disappearing and the underclay becoming sandstone, while the
coal thins away. In some districts there are considerable areas
where the coal is so poor that it is not worth mining; yet, in most
localities, it is a thick bed and yields excellent coal.

"Washouts" are by no means infrequent. The Ras-las is miss-
ing at one place in northern Monmouth. In the Ebbw Valley of the
same county, a great washout was encountered, extending 1,200
yards and causing removal of a section, 116 yards thick, with three
coals, Three-Quarters, Black and Yard. The Ras-las has been
washed out for not less than a mile in the Sirhowy Valley; in the
Bargoed-Taff Valley it has been rendered almost worthless at many
places by wedge-shaped masses of shale, cutting down to or nearly
to the base of the seam, but not below it. These resemble channels
of rivulets, filled with mud before deposit of the overlying rocks.
Local deposits of coal are not unusual. De la Beche[94] saw, near the
village of Bagelly in southern Pembrokeshire, some irregular masses
of stone coal. One, semi-oval, is 140 yards long, 40 wide and 10
deep; four others of similar type were observed. Such coals seem
to characterize the Millstone Grit, since all are local. Cannel is not
abundant; it may be on top or midway in a coal seam, but it is
always in contact with the coal. A seam, one foot thick, was seen
at one place, but it appears to be local.

Strahan[95] has emphasized the plasticity of shale when between
more resistant rocks as shown at some places in the Neath Valley.
There as well as in Cynon Valley near an overthrust fault, the Nine-
feet coal has a layer of shale pressed in to close wrinkles; the coal
has become schistose, weathering into plaquettes, with razor edges,
slickensided and very brittle.

The lower shales and sandstones of the Lower Coal Series have

[94] H. T. de la Beche, "On Geology of Southern Pembrokeshire," *Trans.
Geol. Soc.*, II., Vol. 2, 1829, p. 19.

[95] A. Strahan, Part IV., p. 16; Part V., p. 65.

yielded many trunks of trees, some of which are now in the Museum at Swansea. Many years ago, de la Beche and Logan[96] saw two erect stems near the head of Swansea Valley in Glamorgan; the shale underlying the sandstone was uncovered and found to contain abundance of vegetable remains, proving it to be a vegetable soil, but the statement does not indicate that roots were found attached to the stems. The trees were *Sigillaria;* vertical stems of this type occur frequently.

Coals in this field decrease in volatile content downwardly; the Upper and Pennant coals are gas, while those of the Lower Series are steam coals. But the variation is more marked in all seams as they are followed westward; gas coals become steam coals and the steam coals become anthracitic until at last in the western portion anthracite prevails. It should be noted here that the total thickness of measures in the anthracitic area is very much less than was estimated by the earlier surveyors. Strahan[97] has given an elaborate discussion of the conditions, which well deserves careful consideration.

The South Staffordshire Coalfield.[98]—This is chiefly in the southern part of Stafford but extends into the adjoining counties of Worcester, Shropshire, Warwick and Salop. The region has undergone great disturbance and correlation is hardly possible in some portions, but the relations are clear in the northern districts. The Lower Carboniferous and the Millstone Grit are not reached but the Permian and the Coal Measures are present. The boundary between these formations had not been determined at the time when Jukes wrote; they appear to pass gradually one into the other. No unconformity has been seen between Coal Measures and the deposits taken to be Permian. The latter according to Jukes are from 1,000 to 3,000 feet thick and are extremely variable. Observations by geologists in recent years make more than probable that the lower part of this Permian belongs to the Radstockian Series of Kidston.

The succession below Permian, according to Jukes, is: (1) The

[96] H. T. de la Beche, "Geological Observer," Amer. ed., 1851, p. 482.

[97] A. Strahan and W. Pollard, "The Coals of South Wales," etc., Mem. Geol. Survey, 1908, pp. 65 et seq.

[98] J. B. Jukes, "The South Staffordshire Coal-Field," Mem. Geol. Survey, 2d ed., 1859.

Halesowen Sandstone Group; (2) The Red Coal Measures Clays; (3) The Coal Measures. The first and second are each about 300 feet thick; the Coal Measures have a minimum thickness at the south of about 400 feet and increase northwardly to possibly 1,300.

The Halesowen Sandstones and the Red Clays were thought for a long time to be Permian, but careful study by Ramsay, Hull and Jukes fixed their place finally in the Coal Measures. The Halesowen sandstones are olive-green, brownish to yellow sandstones with two thin coals. They rest on a mass of red, green and mottled clays containing a thin coal, occasionally 9 inches thick. The predominating color is red.

Six persistently important seams of coal are present in the Coal Measures along with a much larger number of thin or dirty seams, which are without value. Among the latter is the Herring Coal in upper part of the section; it is a local deposit, almost worthless as coal, but is of interest because it contains great numbers of fish spines, whence the name given by miners. The remarkable feature in this field is the tendency of coal seams to divide, shown most strikingly by the Thick Coal. This seam, with a roof of black shale, consists of 8 to 14 benches, resting directly on each other or separated by thin partings of clay or shale. Each bench has its own name and retains its character throughout the Thick Coal district. At 2 miles north from Dudley there are eleven benches, with about 36 feet of coal, and partings, in all, amounting to 3 feet; at 1 mile east from Dudley it has 28 feet of coal in 12 benches and less than 2 feet of partings. The Top Slipper and the White, in upper part of the seam, are the best house fuels, but next best are the Sawyer and Slipper in the lowest fourth. The best coking coals are from the Tow, below the top fourth, and the Benches at the bottom, both of which contain much mineral charcoal. These are the conditions near Dudley but changes appear quickly in every direction. Northward, the Roof and Top Slipper pass off as a separate seam, the Flying Reed, which, at Cosely, is 84 feet above the Thick, and at Billston still farther north, the interval is 208 feet. The Flying Reed thins away not far from Billston. The Thick and the Brooch Coals are almost parallel in this area, the Flying Reed diagonaling between them. The other benches of the Thick show a similar

tendency to separate and eventually that seam appears to be represented by 9 seams in a vertical section of about 400 feet. The same features were observed in other seams, though to less extent. The Heathen Coal, at about 20 feet below the Thick in the Dudley area, is at times 43 feet above the Lower Heathen, though these are united in some districts. The New Mine Coal divides near Bentley into two seams, separated by 33 feet of sandstone and shale; and the Bottom Coal parting, ordinarily 1 foot, becomes 50 feet.

The coal seams show as elsewhere variations in thickness and in quality, but these are most marked where the area is near the original limit of the seam. The coal is bituminous throughout. There is little cannel.

Much red and mottled clay and clunch is present above and below the Thick Coal; similar rock occurs near Brierley Hill in the lowest portion of the Coal Measures. Crossbedded sandstone is not wanting and there are many beds of ironstone.

"Rock faults" and "swells" occur only too frequently. At the Old Baremoor colliery, the measures are regular, but at the New Baremoor, the upper portion of the Thick Coal, 9 feet thick, rests on 42 feet of sandy shale, below which are 44 feet of "rock binds" to the Heathen Coal, which at times is replaced by the rock. The lower part of the Thick Coal fringes out on both sides into the rock mass. This is 282 yards wide and it has been followed northward for 400 yards without reaching the end. The bottom of this rock descends toward the north, cutting the lower bands of the coal and the underlying rocks to the Upper Heathen Coal. Thin wedges of sandstone extend into the coal. "Swells" are risings of the floor, often one or two hundred yards long. Jukes thinks that they may have been merely heaps of sand or mud. An important "swell" in the Baremoor colliery showed that partings in the coal thickened appreciably as they approached the swell, with which they united.

There is complete conformity throughout the Coal Measures, Ironstone beds in many cases contain numerous marine fossils.

The North Staffordshire Coalfield, surveyed by Gibson,[98] has the sequence complete. The Upper Coal Measures or the Red and Grey

[99] W. Gibson, " The Geology of Coal and Coal-Mining," London, 1908, pp. 175–182.

Series of Gibson, consists of the Keele, Newcastle and Etruria Marl groups. The Keele is equivalent to the lower part of the Permian of South Staffordshire while the other groups answer to the Halesowen sandstones and Red Coal Measures Clays of that field. The Keele is the Radstockian of Kidston and the other groups form his Staffordian. The total thickness is 2,200 feet. The Grey Series is grouped into Black Band, Middle and Lower Coal Measures with thickness of about 5,600 feet. The Millstone Grit and the Lower Carboniferous, which are reached at the northern side of the field, are without economic interest.

The Keele consists of red sandstones and marls, which are easily distinguished from the Etruria Clays and from those which occur at various horizons in the Middle and Lower Coal Measures. The Newcastle group, largely sandstone, contains four thin coals, but Keele and Etruria are barren.

The Black Band, only 400 feet thick, has three or more coals associated with the valuable deposits of black band, but the important seams are in the Middle Coal Measures, there being 13 of workable thickness and yielding good coal. Most of them average almost 6 feet, seldom reaching 8 feet. Several workable seams are in the Lower Measures. In greatest part, the coals are steam or house fuels, but as they approach the anticline or western boundary of the field, they often change into coking and gas coal.

Marine fossils have been obtained from 9 horizons, the bands being distributed in the column from base of the Coal Measures up to within 700 feet of Black Band. The Keele group has 3 horizons, from which *Spirorbis* has been obtained; these horizons have been recognized in deposits overlying the Halesowen Sandstones in South Staffordshire.

The Lancashire Coalfield.—This is one of the most important in England. Bolton[100] gave a summary description of it in 1897, utilizing results of studies by himself and earlier observers. The Permian deposits in the Pendle range rest on upturned and denuded edges of Coal Measures and pass beyond them to the Millstone Grit.

The Upper Coal Measures, best shown in the Manchester area,

[100] H. Bolton, " The Lancashire Coal Field," *Trans. N. Y. Acad. Sci.,* Vol. XVI., 1897, pp. 227–239.

not far from 2,000 feet thick, consists of reddish shales and sandstones with some thin limestones.   At Bradford colliery, near Ardwick, 7 coal seams, 10 inches to 3 feet 6 inches, were found in a section of about 700 feet.   These have been exhausted.   The Middle Coal Measures, not far from 3,000 feet thick, contains about 10 workable seams, which are practically persistent, though some of them vary greatly.   The coal is apt to be inferior when the thickness exceeds 4 feet, as it is injured by increasing number of thin dirt-bands.   The Wigan cannel has abundance of fish remains and *Stigmaria*.   The sedimentary deposits are extremely irregular, hundreds of feet of shale at one place being represented by a few feet of sandstone at another.   A notable mass of red sandstone, with plant remains and 146 feet thick, rests on the Blenfire Coal at Glodwick colliery in the extreme eastern part of the field.   The Lower Coal Measures, about 1,200 feet thick, has numerous seams but, for the most part, they are thin.   The Bassey or Salts Mine Coal has a maximum of 23 feet, but its coal is inferior and little used.   The Ganister, where thickest, has two benches, Upper Foot and Ganister; when united, the bed has thickness of 8 feet, but in a large area these are separated, the interval reaching 30 feet, and the benches become 2 feet 6 inches and 8 inches.   The Millstone Grit, about 5,000 feet thick, has a thin coal seam in the upper division or Rough Rock, and another lower down.   Casts of *Lepidodendron, Sigillaria* and *Calamites* are numerous in several sandstones and the shales often yield marine fossils.

Hull's[101] studies have supplied most of the information available for this field.   In one of his memoirs, he has described in detail the Wigan area, central in the field.   The Permian, chiefly red sandstone, is not found anywhere in contact with the Coal Measures, but the unconformity is beyond doubt, as Upper Coal Measures are not present at some localities where undoubted Permian occurs.   It contains no coal.

The Upper Coal Measures, about 1,500 feet thick, red and gray sandstones and marls with bands of limestone, has no workable coals.   The Middle Coal Measures, about 2,500 feet thick, and con-

[101] E. Hull, " The Geology of the Country Around Wigan," Mem. Geol. Survey, 2d Ed., 1862, pp. 1–39.

taining all of the thick coals, consists of reddish, gray, yellow sandstones and shales with coals and fireclays. The last are rich in *Stigmaria*. The Coal seams vary much in quality as well as in thickness. In the western part of the area, one portion of the section contains only unimportant coals but in the eastern part, near Wigan, it has, beside some thin streaks, the Haigh Yard, an excellent coking coal, as well as the King and the Cannel. The King has a maximum of 7 feet near Haigh, but thence as a center it thins away toward north, west and south. The Cannel has chief importance near Wigan, where it is 3 feet thick; but it is a lens, thinning away in all directions and it is represented by ordinary coal toward the eastern border. This and the King coal are almost in contact in a considerable area, but northwardly they separate until the interval becomes 60 feet. A cannel, 2 feet 3 inches, is in the St. Helen's section at several hundred feet above the place of that at Wigan, but it disappears northwardly and is represented by black shale at Wigan.

The Lower Coal Measures, about 1,800 feet thick, consists of micaceous flagstones, shales with thin coals. The fourth seam is the Ganister resting on a silicious underclay; the third is the Bullion Coal in whose roof are the "bullions," nodules of argillaceous limestone with *Goniatitis*. Marine fossils are found in the black roof shales. The Millstone Grit, coarse grits, flagstones and shales, has only two or three thin coals.

The sandstones of the Coal Measures and Millstone Grit are often reddish. Those of the Grit are in great part crossbedded, while those of the Coal Measures are described as "generally crossbedded, micaceous, ripple-marked and exhibit sun-cracks, perforations and tracks of annelides and perhaps of mollusks." The roof of the fifth coal of the Lower Coal Measures has vertical *Sigillaria*. The Ince 4-feet coal, near top of Middle Coal Measures, has thousands of vertical stems in its roof throughout the Wigan district. *Anthracosia* and *Anthracopteria* are at several horizons in the Middle Coal Measures and marine fossils are abundant in the Lower Measures. The Wigan cannel contains *Megalichthys, Holoptychius, Ctenoptychius* and *Diplopterus*.

No "washout" is noted by Hull or Bolton.

The Yorkshire Coalfield was described elaborately by Green[102] and his associates. It contains the whole column from Permian to the upper part of the Lower Carboniferous. The succession is: Permian, represented by the Magnesian Limestone, the Zechstein; Upper Coal Measures, perhaps 150 feet; Middle Coal Measures, about 3,500 feet; Lower Coal Measures, about 1,600 feet; Millstone Grit, perhaps 2,000 feet; Yoredale Shales; Carboniferous Limestone is not reached.

Permian and Upper Coal Measures deposits remain at very few localities and for the most part the boundary is obscure, for the relations of the lower beds are in dispute. The Magnesian Limestone rests unconformably upon the rocks in question. Near Pontyfract is a great sandstone, averaging not less than 75 feet, resting on about 40 feet of purple shale and yellow sandstone. It seems to be conformable to the underlying beds but is distinctly unconformable to the overlying Magnesian Limestone. This rock was referred by Smith and by Sedgwick to the base of the Permian, their conclusion being due in great measure to the red color, but Green asserts that this cannot be taken as criterion, for red color characterizes many deposits, which belong undeniably to the Coal Measures. Near Conisborough, the Pontefract is wanting and the Magnesian Limestone overlies 34 feet of very red beds. These rest conformably upon the underlying beds and contain Coal Measures types of *Neuropteris, Sphenopteris* and *Stigmaria*. The Red Rock of Rotherham, a great mass of sandstone and shale, occupies a trough eroded in the Middle Coal Measures. Its age is in dispute and Green declines to commit himself to either interpretation. The mass is certainly unconformable to the Coal Measures but a distinct exposure at one locality shows it distinctly unconformable to the undoubted Permian beds above.[103]

Coal seams are the most nearly constant deposits, because formed in swamps; but swamps must end somewhere; at their margins coal becomes impure, is split by increasing number of clay or sand layers until at length it is replaced with sandstone or shale. Evidence is

[102] A. H. Green, R. Russell and others, " The Geology of the Yorkshire Coal-Fields," Mem. Geol. Survey, 1878, pp. xiii and 823.
[103] Green and Russell, pp. 481–486.

ample, showing that there were many contemporaneous swamps, separated by low divides; their coals are at the same horizons but conditions must have differed locally, for the coal is not the same in all. The existence of such separated areas is distinct at many horizons. The Ganister Coal is present in the southern part of the field but is wanting at the north. The Better Bed is very irregular at the south but is important at the north. The Silkstone Coal is very good near Cawthorne, but thence for a long distance it is badly broken; when the regular seam is reached again at this horizon, it is of different character. More striking is the occurrence of petty isolated swamps, occupying depressions on surface of great sand heaps. Many seams are important only within very limited areas and sometimes a whole group of coals disappears.[104]

The composition of the coal in the several benches of a seam is rarely the same and occasionally the difference is notable. One bench may yield semi-anthracite and another bituminous coal; that from one bench may be caking and that from another may be non-caking. Variations of this type are so numerous as to be commonplace.[105] Cannel, the "stone coal" or miners or, if it contain high ash, "johnnies," is not rare. It has no definite position; it may be at the top or bottom or in the middle of a seam; a whole seam may consist of cannel; but in every case it is lenticular.

The coal varies in thickness as well as in quality. A great many seams are worthless because of ash or sulphur; even in any seam one bench may be clean, another dirty; the coal at one mine may be excellent, at another near by, it may be unfit for use. Faux-mur and faux-toit are characteristic, inferior coal at top or bottom or both being reported from many localities. The faux-mur of the Silkstone Coal is crowded with *Stigmaria* at one mine. The roof of the Ganister Coal has marine fossils in the shale as well as in the "bullions."[106] Marine fossils are in the roofs of several coals in the Millstone Grit. These occur rarely in the Middle Coal Measures and the black shales containing them are thin.[107]

[104] Op. cit., pp. 20, 21, 128, 242, 294, 300, 400, 410, 441 and many others.
[105] Op. cit., pp. 270, 271, 281, 382 and others.
[106] These have been studied by M. C. Stopes and D. M. S. Watson, *Phil. Trans. Roy. Soc.*, Ser. B, Vol. 200, 1908, pp. 167–208.
[107] Green and Russell, op. cit., 40, 63, 70, 71, 110, 230, etc.

Coal seams are rarely single, usually are divided into benches by partings of clay or sandstone which may vary greatly in thickness, though ordinarily the variations are within narrow limits.   At times they are great enough to render the identification of seams more than perplexing.   The Beeston Coal has its two benches in contact at Beeston, but within a short distance they are separated by an interval of 30 feet.   Three seams of the Brown Metals Group show notable changes in relative positions; the interval between Number 1 and Number 2 is 6 inches to 56 feet, and that from Number 2 to Number 3 is from 12 to 66 feet.   Other illustrations are noted, but these suffice for illustration.[108]

Contemporaneous erosion is by no means unusual and at some localities its work was extensive.   In this, one may see evidence of areal changes of level.   Near Penistone, a tunnel has disclosed proof that the region was exposed to denudation for a time in the early part of the Middle Coal Measures.   A hill of Coal Measure sandstone remained, against which shales and two coal seams abut, which were formed in the valley around the hill.   The Handworth Sandstone, southeast from Sheffield, occupies a valley eroded in the underlying shales, but is conformable to the overlying measures. The great red sandstone of Rotherham is unconformable to the underlying measures, occupying a broad valley cut in them.   Coal seams are troubled by "rock faults" of one sort or another.   The Old Hards Coal is wanting in some collieries, having been replaced with a deposit containing pebbles and water worn bowlders.   The Haigh Moor Coal, one of the most important seams, is injured so badly by rock filling the lines of old watercourses, that in one district it is practically worthless.   The "faults" are from 8 to 70 feet across and have northwest-southeast direction.   At times they are irregular, there being broad bands of sandstone, connected by narrow strips, which suggest a series of ponds.[109]

The Silkstone Coal (Middleton Main) is troubled by "splits," which re-unite.   Kendall[110] examined one at Whitwood, where the

[108] Green and Russell, pp. 185–192, 289–298.

[109] Green and Russell, pp. 140, 281, 343–345, 397, 482, 689.

[110] P. F. Kendall, "On the splitting of Coal-Seams by Partings of Dirt," *Trans. Inst. Min. Eng.*, Vol. LIV., 1918, pp. 1–21.

Top Coal rises until it is 29 feet above the Bottom, thence descends until the two benches are again in contact: the same condition is shown in a second drift as well as in a neighboring colliery. This phenomenon is not rare; it has been observed in several seams within the Yorkshire field and geologists have reported its occurrence in other fields. Kendall thinks it is due to the filling of a channel with sand or clay, over which the swamp extended. The originally level top of the in-swept material is now convex while the originally convex bottom is flat. He conceives that during conversion of the peat into coal, the thin borders of the enclosed mass adjusted themselves to the changing thickness of the organic material until the upper surface became convex and the bottom flat. The existence of the gravel deposit has been proved along its west side for about 5 miles; the mass has been crossed by drifts at two places, which show a width of not less than 1,200 feet. Existence of such "splits" is known in the Silkstone Coal at many places, but these have not been connected by continuous workings. Kendall feels justified in asserting that the splits mark courses of ancient streams.

Limestone rarely occurs in the Yorkshire field, the prevailing rocks being sandstones, shales and underclays. The mollusks are mostly *Anthracosia* and *Anthracomya,* which are at many horizons, but undoubted marine forms are present in some thin black shales. The sandstones vary from conglomerate to fine-grained. The coarser rocks are irregularly bedded and in many cases they resemble huge heaps, thinning away in all directions. But there are such deposits, especially in the Millstone Grit, of vast extent and showing little variation in thickness or character. *Lepidodendron* and *Calamites* casts are not rare. Nearly all sandstones, coarse and fine alike, are false-bedded, often with marked current- or cross-bedding, and the finer sandstones frequently are ripple-marked. Shales may be sandy, blocky, passing into sandstones, or they may be argillaceous; sometimes they are black, passing occasionally into cannel. Underclay, known as Spavin or Seat Earth, is usually clay, always unstratified, never splits into layers, breaks into irregular blocks and always contains *Stigmaria,* with rootlets ramifying in every direction. " Many instances have been observed where fossilized trunks

of trees, still standing erect in the position in which they grew, and attached to their roots, rise out of an underclay." At times, the underclay underlies carbonaceous shale. Ganister is a very hard silicious earth, which is seat to numerous coals, especially in the Lower Coal Measures.[111]

Green mentions (p. 123) that an erect stem was seen rooted in a thin seam of coal and passing up into sandstone. Sorby[112] gave a brief note respecting erect stems, which he saw at Wadsley. In preparing the surface for a public building, the workmen exposed a considerable number of such stems. Sorby induced the authorities to construct sheds in order to preserve the finer specimens. The trees appeared to have grown in what is now a clay-like shale, then died and become decomposed to the top of the surrounding mud. They were hollow stumps and were filled with sand like that of the overlying sandstone. The stems are *Sigillaria* and the roots are *Stigmaria*. The largest and best specimen has diameter of 5 feet 2 inches and the top is not ragged. The roots, which bifurcate, are shown well to a distance of 6 feet from the stump. A prostrate stem lay alongside. Five stumps were exposed in a space of 40 or 50 yards.

In the *Northern field,* within Durham and Northumberland, coal seams make their appearance in the Lower Carboniferous and attain some economic importance. These become valuable in portions of Scotland, where they are the source of fuel supply for leading industries. It is unnecessary to dwell on the several fields, as, for the most part, the general conditions differ in the Coal Measures very little from those observed in England. It will suffice to make reference to but one field in Scotland.

The coalfield of the *Lothians* is in Edinburghshire and Linlithgowshire. It was studied long ago by Howell, Geikie and Young but more recently was examined in detail by Cadell.[113] The suc-

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[111] Green and Russell, pp. 14, 17, 37, 58, 60, 97, 114, 140, 300, 323, 402, 437, 470, 496, 649, 666.

[112] H. C. Sorby, "On the Remains of a Fossil Forest in the Coal Measures at Wadsley, near Sheffield," *Quart. Jour. Geol. Soc.,* Vol. 31, 1875, p. 458.

[113] H. M. Cadell, "The Geology of the Oil Shalefield of the Lothians," *Trans. Edin. Geol. Soc.,* Vol. VIII., 1901, pp. 116 et seq.; Mem. Geol. Survey, 1906, 1910; "The Story of the Forth," Glasgow, 1913.

cession as determined by him is: Coal Measure, 1,000 feet, red sand-stones above, coal seams in lower portion; Millstone Grit, 500 feet, without coal seams; Carboniferous Limestone, 2,000 feet, limestone, volcanic bed, coal seams, the Hurlet limestone at base; Calciferous Sandstone, divided into (1) Oil Shale Group, 4,000 feet, with 2 thin coals in upper part and oil shales in middle and lower parts; (2) Cement Stone group, without coal and resting on the Old Red Sandstone.

The great Carboniferous Limestone, thousands of feet thick in portions of England, is split up here into not more than a half dozen beds, each at most 50 feet thick, with sandstones, shales and coal seams in the intervals. There are many coals, almost 50, and at least 17 of them exceed 2 feet in thickness. One has maximum of 8 feet and another of almost 6 feet. These are thoroughly typical and rest on underclays with abundant *Stigmaria* in place. Iron-stone, economically important, occurs at many horizons. At Bridge-ness in the Bo'ness area, Cadell more than once explored an old forest exposed by workings on the Craw Coal. On one occasion, he counted 113 stumps, *Sigillaria*, distributed along 400 yards of roadway. They were arranged in clumps and were from two and one half inches to two and one half feet in diameter. The stems in great proportion were prostrate. Cadell conceives that they were broken off by a violent wind from the south, as most of them lie over toward the north. The vertical stumps were filled with fer-ruginous mud and the bark remained as coal. One of the sand-stones is ripple-marked, has casts of fresh-water shells and flattened heaps of worm-castings.

Two thin coals, Two-feet and Houston, are about 1,000 feet below the Hurlet limestone; they are true coal seams but are very high in ash. The Houston, at one place, is 5 feet 9 inches in 4 benches, including a 2-inch cannel, directly under the top bench; at another, it is somewhat more than 11 feet and has a bench of oil shale. The coal is soft, but at its best is pyritous and dirty.

The notable feature of the group is the Oil Shales, which is easily recognized. It gives a brown streak, is tough, resists the weather and is not gritty. The thickness varies; at times a deposit disappears or passes into ordinary shale; at others, it may reach 15

feet, including partings of ordinary clay. It is finely laminated, but this feature is distinct usually only in " spent clay," that which has been treated. Thin streaks have been discovered in shales within the Carboniferous Limestone, but they are unimportant. Four important horizons are in the Calciferous Sandstone, the chief one being at 3,200 feet below the Limestone base. At some places, the shale has many impressions of fish; at others it is composed almost wholly of minute cyprids and crustaceans, so abundant that the shale resembles fine linseed cake. With these are fragments of ferns. The lagoon of deposit had an area of not less than 330 square miles. The best shale has fixed carbon, 5; volatile, 25; ash, 70 per cent. A yield of 30 gallons of oil per ton is that of good shale.

The Craigleith Sandstone, at base of the Calciferous, is well marked in the Edinburgh area, whence Witham obtained his tree, which, evidently, was a " snag." Brown[114] described this sandstone as made up of lenses, thinning out in all directions and dovetailing. Coaly laminations, derived from drifted material, are numerous. The water was shallow; sun-cracks, worm tracks, ripple-marks, rainprints and footprints of labyrinthodonts have been observed. Brown found in the quarry a large block of current-bedded sandstone containing several casts of *Lepidodendron*. The largest fragment, 3 feet long and 14 inches wide, was somewhat compressed and retained some of its bark, converted into coal. At one side in the interior was a thick layer of brown material, but the rest of the cavity was filled with sand. The brown substance contained numbers of the gasterpod, *Platyostomella*, and the " nests " were formed before the sand was deposited, for the laminæ of the latter curve around them. This gasteropod was probably an estuarine form. At another locality, it is associated with *Spirorbis pusillus*, which may indicate marine conditions. At the same time, the Craighill species has peculiarities, which lead Brown to suggest that, like *Hydrobia*, the genus may have had fresh-, brackish- and salt-water species. The question of adjustibility of molluscs to changing marine or fresh-water conditions is unimportant. They can and do

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[114] C. Brown, " On the occurrence of Gasteropods (*Platyostomella scotoburgalensis*) in a *Lepidodendron* from Craighill Quarry, Edinburgh," *Trans. Edinb. Geol. Soc.*, Vol. VII., 1897, pp. 244–251.

adjust themselves.   De la Beche[115] states that *Voluta magnifica* lives high up in brackish water near Port Jackson, Australia, and that an *Arca* inhabits the fresh-water of Jumna River at 1,000 miles from the sea.   G. B. Sowerby had informed him that an *Astarte* and a *Cardita* had been found in pools on the ice near Melville Island, and that a *Nucula* lives in the Ganges at Banda.   An *Anodon* thrives in brackish water at the Commercial Docks of London, where it is associated with a *Mytilus* brought from the Danube.   He cites Mc-Culloch, whose experiments proved that many marine fish and crustaceans can become habituated even in fresh-water.   Almost 80 years ago, J. W. Bailey discovered a strange commingling of fresh-water and marine types in the Hudson River near West Point, where one reaches practically the limit of brackish water.

South America.

Brazil.—Permo-Carboniferous rocks have been reported from several countries in South America and have been described in admirable memoirs; but such deposits are most important in Brazil, where, according to Branner,[116] "the Permian is, *par excellence,* the Brazilian series."   They were recognized by Eschwege in 1832 and, since that time, they have been studied in the several states by many geologists, among them, F. de Castelnau, O. A. Derby, C. F. Hartt, Oliveira, P. W. Lund and M. A. R. Lisboa.   For the most part, the examinations were reconnaissances, sufficing to prove extent of the deposits, but giving detailed information respecting few areas. Whether or not the Coal Measures are present remains to be determined.   The Permo-Carboniferous has coal in the southernmost states.

Hartt[117] states that Perigot discovered the coalfields of southern Brazil in 1841.   A detailed study of the deposits in Santa Catharina was made by U. Plant, whose report, made in 1869, was republished by Hartt.   On the Rio Candiota, Plant found, in a section of 70

[115] H. T. de la Beche, " Researches in Theoretical Geology," Amer. ed., N. Y., 1837, pp. 224, 225.

[116] J. C. Branner, " Outlines of the Geology of Brazil," *Bull. Geol. Soc. Amer.,* Vol. 30, 1919, pp. 211.

[117] C. F. Hartt, " Geology and Physical Georgraphy of Brazil." Boston, 1870, pp. 519–531.

feet, 56 feet of coal in four seams, 3, 11, 17 and 25 feet.   Coal from
the 17-feet seam was tested by steamers on the Rio Grande with
good results, though the ash is high.   The coal is caking and yields
from 6,700 to 8,198 cubic feet of gas with 5 to 5.8 candle-power.

Almost two score years later, White[118] examined the coal areas
of Rio Grande do Sul, Santa Catharina, Paraná and São Paulo, the
southern state of Brazil.   His conclusions did not justify hopes
based on reports by earlier observers.   The deposits were laid down
on an irregular surface of granite, which, at times, is within a few
feet of the lowest coal, at others, separated from it by a considerable
thickness of rock.   The succession, near Minas in Santa Catharina,
is: Santa Catharina System, composed of São Bento Series, 900
meters; Passa Dois Series, 228 meters; Tubarão Series, 280 meters.
The São Bento Series, red sandstone and shales, is capped by a
great thickness of eruptive rocks and is assigned to the Triassic.
The Passa Dois Series, shales with thin limestone at top, is without
coal and is referred by D. White to the Damuda series of India.
The Rio Bonito sandstones and shales of the Tubarão Series, con-
taining the coals, are 158 meters thick near Minas and have 5 coals;
at one place in São Paulo, 170 meters and no coal; at one in Paraná,
270 meters and no coal; at one in Rio Grande do Sul, the group is
but 57 meters with one thick and four thin coals; while at 18 kilo-
meters farther south it is 145 meters with one thick and 13 thin
coals.   In the greater part of the region, the Rio Bonito consists
chiefly of yellowish to grayish white feldspathic sandstones, which
are poorly consolidated; in much of Rio Grande do Sul, however,
shale predominates.

The coals were seen first in Santa Catharina, where, near Minas,
5 seams were examined, Treviso, Barro Branco, Irapuá, Ponte Alta
and at bottom, Bonito; but at 60 miles northward, only one seam,
probably Barro Branco, was seen.   In the northern states, Paraná
and São Paulo, the distribution of coal is indefinite; at best the
seams are very thin and they are wanting in many districts.   Even
in Santa Catharina and Rio Grande do Sul, the seams are so irregu-
lar that they may be regarded as local, the only really persistent

[118] I. C. White, Commisão de Estudos de Carvão de Pedra do Brazil,
Relatorio Final," Rio Janeiro, 1908, pp. 1–300.

horizon being the Barro Branco. Southwardly, the coal measures pass under cover not far south from Minas and come again to the surface near São Jeronymo in Rio Grande do Sul, where the Treviso is represented by shale, the Irapuá by shale and coal, but the Barro Branco or São Jeronymo is important. At Serro Partido near Rio Candiota, where Plant obtained his section, the section as measured by White is, thicknesses being given in meters, (1) shale, sandstone and concealed, 19.28; (2) coaly shale, 0.91; (3) shale with plants, 2.29; (4) coal and shale, 0.305; (5) clay, 1.52; (6) shales, dark and yellow, plants in latter, 1.04; (7) São Jeronymo, Coal, 4.78, consisting of (a) slaty coal, with *Sigillaria* in roof, 1.22, (b) blue clay, 0.51, (c) carbonaceous shale, some coal, 1.22, (d) impure coal, 1.83; (8) clay and shale, 6.59; (9) interval in shaft, reported, 12.19; (10) Irapuá Coal, 0.20 to 0.36. It is evident that the earlier observer mistook dark shale for coal.

The one persistent coal horizon is the Barro Branco-São Jeronymo, but it varies greatly. It is usually triple in the Minas region, though more divided at times, the thickness varies from 0.93 to 2.20 meters, and the coal is described as " good " to " fairly good " and " slaty." In Rio Grande do Sul, it has, at one place, 2.68 thickness with a parting of clay, only 10 centimeters, but at other places this parting is from 3 to 5.30 meters. The other seams are traceable in the two southern states, but for the most part they are thin. The roof at most places is a leaf-bearing shale and the floor is clay or clay shale. One can hardly recognize faux-mur or faux-toit owing to character of the coal.

The coal is always high in ash and usually in sulphur. Analyses of that from the one important horizon show:

	Barro Branco.	São Jeronymo.
Moisture	1.01 to 1.21	3.43 to 6.05
Volatile	7.64 to 26.00	22.98 to 29.09
Fixed Carbon	35.34 to 54.63	37.52 to 44.20
Ash	24.88 to 28.38	23.04 to 31.17
Sulphur	1.58 to 11.42	0.60 to 12.96

The sulphur is present as pyrite and it, as well as a great part of the ash, can be removed by washing. Briquettes, made from washed coal, have from 8 to 14 per cent. of ash and 0.64 to 1.31 of

sulphur. The natural coal is inferior everywhere; evidently, the swamps, in which it was formed, were subject to frequent overflows of muddy water. There is no reason for believing that the sea invaded the region during the Permian.

D. White,[119] in the same volume, publishes an elaborate discussion of the plant remains and conditions. A shale in the Bonito Coal is crowded with megaspores, probably of *Sigillaria,* and a fine-grained flinty fireclay is filled with roots tentatively referred to *Vertebraria.* He found *Vertebraria* in the Barro Branco-São Jeronymo Coal as well as in shale near Minas and in roof of the Irapuá Coal. *Reinschia australis* Bert. and Ren., was observed in a fragment of boghead picked up on the coast. This material, he is convinced, is not from Brazil but was dropped from an Australian vessel carrying Kerosene Shale.

The roof of the Irapuá Coal contains *Glossopteris* and *Noeggerathopsis;* that of the São Jeronymo, at one locality, contains carbonized roots along with matted leaves of *Noeggerathopsis,* while, at another, it is an impure coal, whose dull layers are full of leaf and wood material in charcoal, and at a third, the dull layers consist largely of charcoal derived from *Lepidodendron, Sigillaria,* etc.

He finds Gondwana forms in the lowest portion of the coal measures. He is convinced that the Tubarão Series is practically equivalent to the Talchir-Kharharbari of India, Newcastle of New South Wales, Bowen of Queensland, etc. The Passa Dois Series is most probably equivalent to the Damuda Series.

[119] D. White, The same, pp. 337–607.

GEOGRAPHIC ASPECTS OF THE ADRIATIC PROBLEM.

By DOUGLAS JOHNSON.

(Read April 22, 1920.)

No question before the Peace Conference presented greater difficulties than that of Italy's eastern frontier. The Adriatic problem is essentially a geographic problem. It subdivides itself into a question of naval geography and a question of land frontiers.

The mountainous, ragged eastern coast of the Adiratic with its numerous harbors, is in strong contrast with the low, simple western coast where harbors are few in number and inferior in quality. Any naval power on the eastern coast must find itself possessing immense advantages over Italy. A fleet taking refuge in one of the Italian harbors is visible from far out to sea because of the flatness of the coast, whereas vessels secreted along the eastern shore are invisible behind mountain barriers. From the low western coast observation of an approaching squadron is limited as compared with the better observation enjoyed by those on the dominating heights of the eastern shores. Coast defense artillery has little choice of inferior positions on the Italian side, and unlimited choice of excellent positions on the eastern coast. A fleet emerging from one of the western harbors to give battle may be taken unawares before it can develop its battle formation; while a fleet manœuvering behind the protective fringe of islands along the east coast may emerge from a number of passages simultaneously and assume a predetermined formation without delay. The Italian submarines, scouting along the eastern shores, find the bottom rough and deep, so that lying in wait for an enemy is a danegrous procedure; while the Austrian submarine finds shallow water and a smooth bottom upon which to lie concealed, pending the passage of an intended victim. The clear waters along the eastern coast reveal hidden mines or submarines to the scouting hydroplane, while the murkier

waters bordering the Italian coast make it difficult for Italian observers to locate enemy submarines or mines sown by enemy craft. Even in the matter of illumination the Italians are at a great disadvantage. Raids are usually made by crossing the sea under the cover of darkness and appearing off the enemy coast in the early morning. When an Austrian raider thus appears off the Italian coast, his objective is well illuminated by the rising sun; whereas the Italian artillerymen must look into the sun when firing upon their attacker. And when an Italian squadron appears off the eastern coast, it finds its objective obscured by the shadow of high cliffs and must look toward the sun when developing its fire, the while its own vessels are so well illuminated as to form excellent targets for the east coast batteries.

On such arguments as these Italy might claim the need of special consideration in the Adriatic. Without taking time to develop the counter arguments I will merely note that in the proposals which have been made for the settlement of the Adriatic question, complete security has been offered to Italy by granting her Pola, Valona and a central island group, three points which have long been recognized as the strategic keys of the Adiratic.

On ethnographic grounds Italy could claim but little east of her old land frontier. She might ask for Gorizia, Trieste and a narrow strip along the west coast of Istria; but beyond this both Italian and Jugoslav geographers agree that Italians are few in number and scattered throughout an overwhelming mass of Jugoslavs. On topographic grounds, and to preserve the geographic and economic unity of the Isonzo basin, as well as to afford Italy reasonable protection on the east, her frontier in this region might be pushed up the slopes of the Julian Alps to the crest dividing the westward from the eastward flowing rivers, and in Istria to the main backbone ridge of Monte Maggiore. This would subject 370,000 Jugoslavs to Italian rule, and leave less than 50,000 Italians in Jugoslavia.

But Italy demanded much more than this. East of this line she asked for the Idria district with its valuable mercury mines, and its 20,500 Jugoslavs with practically no Italians; for a large district cutting the Fiume-Laibach railway and containing 40,000 Jugoslavs

with less than a hundred Italians; and for all of Istria, and the shores of the Gulf of Fiume to and including the port, as well as islands which would close the gulf and make it an Italian lake. In the long negotiations looking toward a reduction of these claims, Italy's persistent demand for explicit or virtual control of the port of Fiume proved the most serious stumbling block.

The peculiar strategic value of Fiume from both the economic and military point of view is at once apparent. A glance at the map will show that the Dinaric Alps, a broad belt of wild and rugged mountainous country, intervenes between the interior of the Balkan peninsula and the Adriatic Sea. South of Fiume this range is crossed by but two or three narrow-gauge railroads, wholly inadequate to serve the commercial needs of the interior. The only standard gauge road crosses the mountain barrier at its narrowest point, opposite Fiume. The geographic conditions are such as permanently to preclude any cheap and effective rail transport across the broad part of the barrier; hence Fiume, advantageously situated opposite the narrowest part, and at the head of a sea that makes water transportation both cheap and easy, is the inevitable economic outlet for the northern part of Jugoslavia. Practically the whole standard gauge railroad system of Jugoslavia is in the latitude of Fiume, because the fertile river plains of the country are almost entirely confined to that region; because nearly two-thirds of the population lives in these plains and valleys; because railroad construction is easy and comparatively inexpensive there; and because there is sufficient local traffic to maintain the roads and keep rates down. Thus it will be seen that the life of the Jugoslav nation is to an unusual degree concentrated in the north of the country; and as the railroad system upon which this economic life depends has its only direct outlet to the sea at Fiume, it may well be said that the power that holds Fiume holds the life of an entire nation in its hands.

Not only do Austria and Hungary, and to a considerable degree Czechoslovakia and the newly enlarged Rumania look to Fiume as an important economic outlet, but all the outside world desiring to trade with central and southeastern Europe via the Mediterranean

route has a very real interest in the settlement of this question. According to the settlement offered Italy, Trieste would go to Italy and Fiume to Jugoslavia. The Italian port could then supply the hinterland by a line of rail which would not have to cross Jugoslav territory; while Fiume could supply the same hinterland by a line not touching Italian possessions. This would insure freedom of commerce to all, both ports and routes being secure from possible interference by a jealous neighbor. All the world would profit from such an equitable arrangement, assuring equality of opportunity to all.

Italy's economic interest in Fiume is necessarily slight. Even if one granted her demand that more than half a million Jugoslavs be placed under her dominion in order to extend her frontier to include the few thousand Italians in Fiume, the port would remain at the most remote corner of her territory. It is hardly conceivable that Italian commerce would pass by the much more convenient Trieste in order to reach a more distant and less serviceable port.

There was no natural harbor at Fiume. The artificial harbor was constructed by the Hungarian government at great expense. Before the war it was found to be inadequate, and plans were formulated for its enlargement and improvement. These plans will entail a very large expenditure of government funds, and it is difficult to believe that Italy will ever be prepared to expend her millions for the development of an artificial peripheral port to compete with the more accessible port of Trieste. Especially is this true when we remember that Italy considered it essential that her eastern frontier should be pushed 12 or 15 miles east of Trieste for the protection of its port works. At Fiume the frontier proposed by Italy would pass through one of the basins of the port, so that a hostile advance of a few thousand yards would deliver the entire port into enemy hands. If Italy could not afford to develop Trieste without adequate territorial protection, she could hardly afford to develop the much more remote Fiume without any protection. And the supreme interest of the people of Fiume, Italians as well as Jugoslavs, is to have their port become one of the great commercial gateways of Europe.

A study of the geographic aspects of the Adiratic problem leaves no escape from the conclusion that the interests of Jugoslavia, of Central Europe, of the outside world, and of the people of Fiume itself, demand that Fiume should be assigned to Jugoslavia when Trieste is assigned to Italy.

COLUMBIA UNIVERSITY,
     April 22, 1920.

CERTAIN ASPECTS OF RECENT SPECTROSCOPIC OBSERVATIONS OF THE GASEOUS NEBULÆ WHICH APPEAR TO ESTABLISH A RELATIONSHIP BETWEEN THEM AND THE STARS.

By W. H. WRIGHT.

The Lick Observatory has carried on during recent years a number of researches on the nebulæ. About two years ago these had taken a form sufficiently substantial to serve as the basis of a publication, and a number of memoirs entitled *Studies of the Nebulæ* were prepared at that time. Owing to industrial conditions developed by the war the printing of these papers was greatly delayed, and they have only now been issued as Volume XIII. of the *Publications of the Lick Observatory*. As one of the contributors to that work I have been asked to present some account of the investigation with which I am particularly concerned. It may be said that my own observtions are spectroscopic, and are confined to the gaseous nebulæ.

In attempting to give a comprehensive account of a survey in a relatively new field one is likely to be embarrassed by the heterogeneity of the material that presents itself for description. Astrophysics is essentially such a new field, and it is sometimes difficult to wander very far from what we consider, perhaps too confidently, the well-worked border without being overwhelmed with a diversity of new, and totally unexpected facts, which frequently serve to control the path of progress. Whatever was the original purpose of the quest, it is likely to have become modified by factors of its own development in such a way that the accumulated information bears apparently on a number of problems, and offers a complete solution of none of them. At any rate that has, in a sense, been the course of the present investigation. It had its beginnings in an at-

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tempt to measure the wave-lengths of the nebular lines somewhat more accurately than had been done before; in its present stage it is concerned chiefly with the distribution of the radiations through the nebulæ. There have been intermediate developments. The rather meager accumulation of material that is available is somewhat heterogeneous, and can hardly, in its entirety, be presented to an audience of general scientific interests. I shall, therefore, with a full sense of the limitations of the observations, undertake to consider them from the point of view of the relationship of the nebulæ to the stars. Such a relationship can be regarded as an element of the theory of stellar evolution, and it may be well to recall a few of the ideas that at present form the substance of that theory.

At the mention of the term "stellar evolution," in a general scientific gathering, one frequently becomes aware of an atmosphere of amused toleration, or tolerant skepticism. The raising of a brow, or the birth of an indulgent smile, diffuses such an atmosphere with the velocity of light. It is not my purpose to proselyte in the interests of any particular scientific creed, but inasmuch as we are approaching the observations from the point of view of stellar relationships, it may be well to recall the principal consideration that has led astronomers to the belief that such a thing as stellar evolution exists. The conception of stellar evolution finds its justification very largely in the principle of the conservation of energy. The sun and the stars are continually pouring out into space a simply inconceivable amount of energy in the form of radiation. We are all familiar with comparisons designed to help us sense the prodigious outflow. Perhaps as good a one as any is represented in the statement that if the surface of the earth, land and sea, were covered a mile deep with coal, the quantity of fuel represented would supply the output of solar heat for about a minute. Some of the stars radiate several thousand times as much heat as the sun. Whatever the nature of the process by which the energy is at present being replenished, it is impossible to conceive of the expenditure going on forever. Sooner or later the star must cool, and, through alteration in its temperature, suffer a change in its physical state. This process of change had been termed the evolution of the star.

On account of the enormous distances of the stars the principal

means we have of studying their physical conditions is by spectroscopic analysis of their light, and we must therefore look to that to furnish the greater part of the material for whatever study can be made of the processes of stellar change.

Among the spectra of the heavenly bodies there is the greatest diversity; still, as Secchi first showed, they can nearly all be segregated into a comparatively few fairly homogeneous groups. While
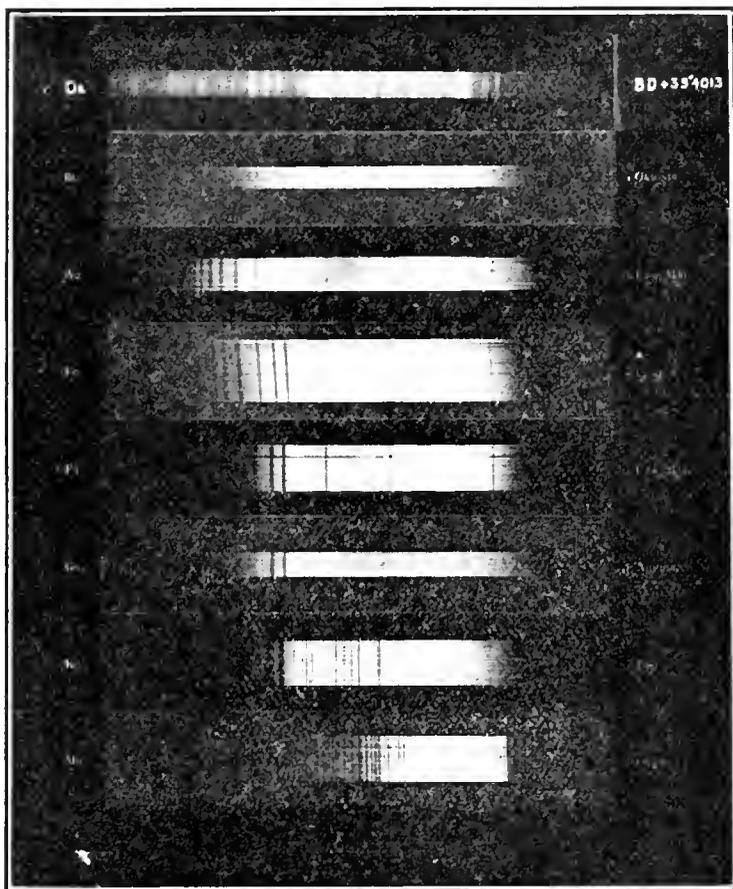
FIG. 1.

the general validity of Secchi's classification is recognized , it is not sufficiently comprehensive nor exact to describe the great variety of spectra that have, in recent years, been made available for study through the aid of photography. The system referred to here will be that of the Draper classification, developed at the Harvard Col-

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[1] The writer wishes to acknowledge his indebtedness for this illustration, excepting the first spectrum, to the Draper Catalogue (*Ann. H. C. O.*, **91**), from which it is copied and where it serves as frontispiece to illustrate typical stellar spectra.

lege Observatory. The nature of the arrangement in that system is indicated by the typical spectra of the illustration (Fig. 1). The top spectrum is that of a Welf-Rayet star, or Class O star in the Draper system; following it is one of Class B, in which the dark lines of helium are strong. In the next the rhythmic hydrogen series predominates, while, as we go down, that in turn fades, and metallic lines, notably the strong calcium doublet, become pronounced. It will now be observed that while the sequence on the screen is based entirely on the occurrence of lines in the spectrum, another characteristic is shown as we pass from the top to the bottom of the picture, that is, the cutting off of the spectrum from the left side. This means the impoverishment of the violet end of the spectrum, as compared with the red. In other words we pass from stars that are bluish white, through those that are yellow to those that are red. It is one of the facts of our ordinary experience, fortified by elaborate theory and experiment, that this succession of color phenomena marks the cooling of an incandescent body; and the view has been generally adopted that exhibits such as that on the screen represent the spectra of stars in an order of continually decreasing temperature. Evidence confirmatory of this opinion is afforded by the fact that the spectral lines in the upper spectra are found in the laboratory to be characteristic of high temperature, while some of those in the lower are due to chemical compounds which can exist only in a comparatively cool environment.

Astronomers have, for a long time, thought that the spectral sequence here indicated offers the basis for inference with respect to stellar evolution, though there is not unanimity of opinion as to just how the evidence should be interpreted. It is manifestly impossible in the available time to indicate the many points of view from which the evidence has been considered. Probably a majority of those who are interested in such matters are inclined to interpret directly the sequence in the illustration, that is, to assume that the upper spectrum is one of the newly formed star, and that the following spectra are of stars in successive stages of development. This is equivalent to the hypothesis that a star originates at a high temperature and cools continuously throughout its period of visibility, fading out as a dim red object. This view is opposed

by some others, chiefly by Sir Norman Lockyer, who regard it as out of harmony with the well-known laws of gaseous equilibrium. According to Lane's law a star, assuming it to be a gaseous mass, should grow hotter while contracting as the result of the loss of its heat.[2] This rise in temperature should continue until the material, through increased density, ceases to be a perfect gas, after which the temperature will fall. According to this conception a young star would be comparatively cool, and therefore, red; with increasing age it would grow hotter, achieve a maximum, and then cool off. There would be a succession of colors corresponding to temperature. Now all of the spectra of the red stars are not alike, nor are those of stars of the other groups, and in order to accommodate the spectral sequence to his hypothesis Lockyer has divided the red, yellow, and white stars into two groups which I shall for simplicity distingiush by means of subscripts. The red stars are the extremes of this system, the Red_1, according to Lockyer, being the youngest and the Red_2 the oldest of all the stars. Next to them come the corresponding groups of yellows and whites. I have attempted to diagram these two systems in a very elementary way by means of these curves (Fig. 2), in which time is measured from left to right, and temperature vertically. The hypothesis first referred to is represented in the figure on the left. Here we start with the hottest of all stars, those of the Wolf-Rayet or Class O group, and with falling temperature follow through the course of a star's life. The second hypothesis is outlined in the right-hand figure. These two diagrams are inadequate to represent all the views, and modifications of views that are held in one quarter or another. They

[2] It has been pointed out by Schuster (*Astrophysical Journal*, 17, 165, 1903) that Lane's law concerns itself with the temperature of the star's interior, while what we observe is the temperature at the surface. It is not certain that there is a simple relation between the two, since the surface temperature of a radiating body represents merely a balance between the rate of radiation and the rapidity with which heat can be supplied from the interior to make good the loss. If the transfer from within is effected mainly by convection the readiness with which it takes place will depend upon the force of gravity, that is to say upon the mass and dimensions of the star, as well as upon the temperature of its interior. It is therefore extremely doubtful to what extent the inferences from Lane's law should be expected to harmonize with the observations of the surface temperatures of stars, to which we are limited in our investigations.

are intended to represent only in the most general way the two classes or hypotheses which form part of the very speculative subject of stellar evolution, and are introduced to show at a glance the especial interest which attaches to the relationship of the nobulæ to one or the other of the stellar groups. It may be said with regard to the respective merits of the two hypotheses that the first has in its favor a pretty straightforward sequence of spectral similarities, with spectral evidence in the earlier groups of high temperature and intense electrical excitement, which fades through the spectra in the order indicated, while the second appears to receive support from
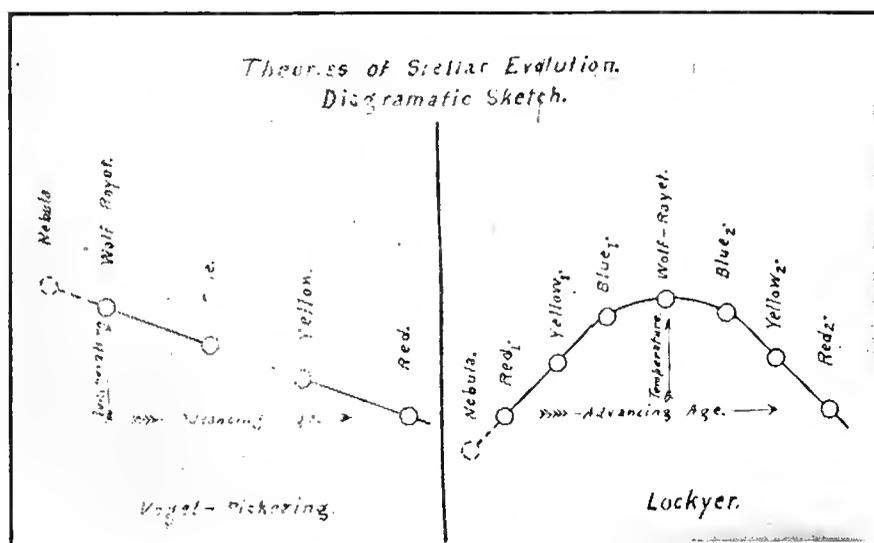
FIG. 2.

considerations of a general nature which indicate an exceptonally low density for some of the red stars.

It will be observed that both of these hypotheses assume the nebulæ as antecedent to the stars.

In searching for a nebular origin there are four general classes of objects among which it is necessary to distinguish: the spiral nebulæ, the extended amorphous nebulæ with continuous spectra, the extended gaseous nebulæ, and the small gaseous, or planetary nebulæ. With respect to the spirals, it is doubtful whether they belong to our stellar system, and in any event they are bodies of such stupendous size and mass that they can not be regarded as single stars in the process of formation. We know little of the

second group, the extended white nebulæ.[3] The gaseous nebulæ, from their peculiar distribution along the Milky Way, are undoubtedly to be regarded as forming part of our system of stars, and in that sense furnish available material for our speculations. Furthermore they are the only ones whose spectra we are able to study with any degree of completeness, so that from the point of view of spectroscopy, our hope, for the present, must lie very largely with them. For these and other reasons it is between the stars and the gaseous nebulæ that a relationship has generally been sought. The connection has been claimed between the nebulæ and the Class O, or Wolf-Rayet stars, by those favoring one hypothesis on the basis of certain spectral similarities, and on the rather peculiar distribution of both groups of objects along the path of the Milky Way. The opposition, on the other hand, points to the occurrence of the bright lines of hydrogen in both the gaseous nebulæ and some of the red stars; and quite recently a number of the nebulium lines have been observed by Merrill at Mount Wilson to occur temporarily in the spectra of stars of that class. It will be seen that as between these two hypotheses, the matter of this connection with the nebulæ is one of vital concern. If the gaseous nebulæ can be shown to be related to the Wolf-Rayet stars the first hypothesis is strengthened, if, on the other hand, the connection is with the red stars the favor goes to the other theory. The relationship of the nebulæ to the one group or the other may then, in a sense, be regarded as a criterion to determine between these two conceptions as to the nature of stellar evolution.

I find it difficult in these remarks to be brief, and at the same time to avoid seeming to imply a degree of definiteness with respect to inferences that may be drawn from the evidence, and in fact, with respect to our conceptions of cosmogony, which would not be justified either by the available observational data nor by the present scientific point of view. I believe that astronomers, particularly observers, are, as a rule, not disposed to dogmatize on the subject

[3] These nebulæ like the gaseous or bright-line nebulæ favor the Milky Way, and are therefore to be regarded as members of our sidereal system, but our knowledge of their spectra is so limited that it does not afford a secure basis for speculation as to their physical constitution.
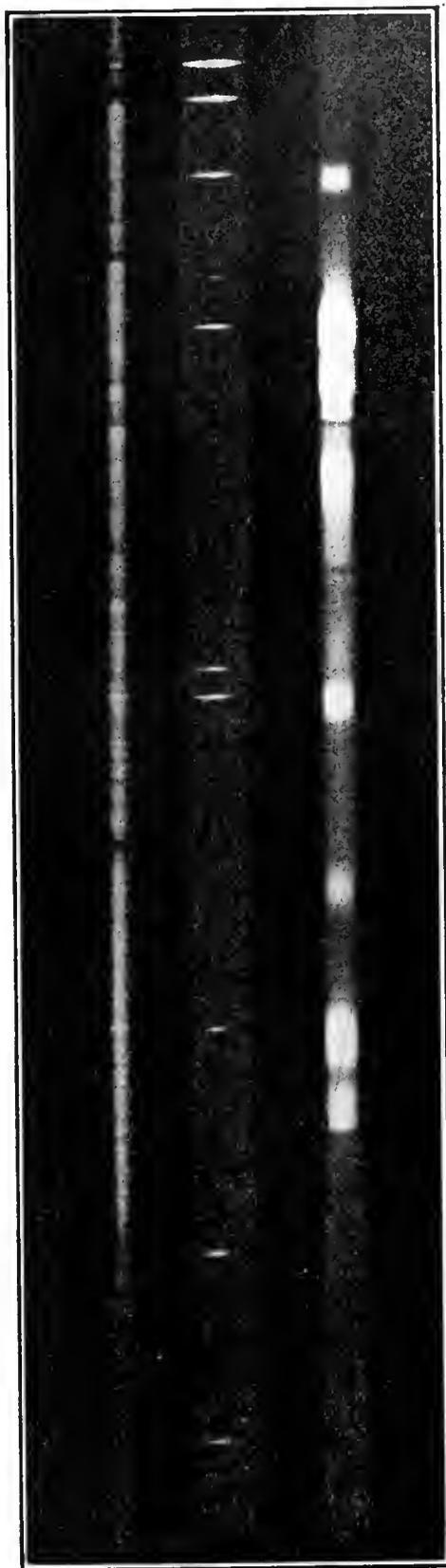
FIG. 3.

of stellar evolution, and there is an opinion, which I myself share, that we have not as yet sufficient evidence on which to found a secure conception of cosmogony; still any fact is of scientific interest only in so far as it is related to others, and it is therefore necessary to examine all observational material from every reasonable point of view, and to appraise as well as possible its significance. It is for this reason that the present observations, in spite of their meagreness, are examined with respect to their bearing on our present notions of stellar evolution.

The gaseous nebulæ present a bright line spectrum such as is shown in the middle section of Fig. 3. The lines on the extreme right are the so-called first and second nebular lines. They are of unknown chemical origin. The third is due to hydrogen. The fourth strong line is the remarkable one at wave-length 4686 A, regarded, since the advent of the Bohr theory of the atom, as due to the recombination of completely ionized helium. It will, in these remarks, be referred to as the fourth nebular line. The upper spectrum is that of a red, the lower one of a Class O star. The red star has, like the nebula, narrow bright lines due to hydrogen and nebulium.[4] The Class O spectrum is composed of broad bright bands, a few of which correspond in position with the bright lines in the nebula. While having points in common, the three spectra are distinct. There has in past years been much discussion of their possible relationships, but until comparatively recently no certain connection had been established between either of the two outside spectra shown on the screen and the nebular spectrum in the center. The evidence which we have here to discuss is afforded by an examination of the nuclei or small star-like condensations in the planetary nebulæ. The investigation of these minute objects is somewhat exacting in its demands on the resources of observation, for the spectrum must be isolated from that of the rest of the nebula. When this is done they are found in many instances to exhibit the spectra of Class O stars. The diagram (Fig. 4) will indicate the method of making the observations. The sketch on the left represents the telescopic image

[4] The spectrum here shown is that of the variable R *Aquarii,* already mentioned as having been found by Merrill to exhibit, temporarily, the lines of nebulium.

of a star, assumed to be surrounded by envelopes of two kinds of gas, one larger than the other. The vertical parallels represent the slit of the spectroscope. To the right is the spectrum of the system showing bright gaseous lines, and the continuous spectrum of the star. The length of the bright lines is seen to offer a measure of the extent of the gaseous distribution. The objects are so faint that they can be observed only by photographs of long exposure, and in making these it is necessary to keep the nebula at precisely the
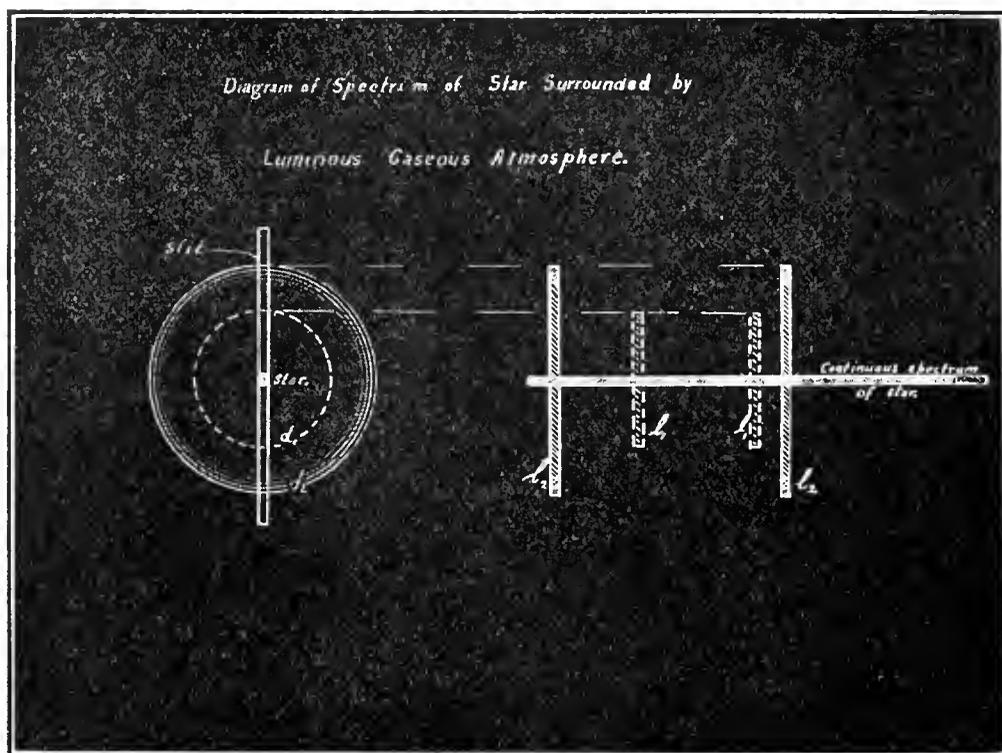
FIG. 4.

same position on the slit during the entire time, otherwise the record would be hopelessly confused. This is a tedious, and sometimes difficult task.

Turning now from the diagram to a real subject, Fig. 5 records the spectrum of the bright planetary in Andromeda. The fourth nebular line is shorter than the others, which indicates that the peculiar conditions that are favorable for its production obtain only comparatively close to the central star, in fact very largely within the inner area indicated in the preceding sketch. The spectrum of the nucleus is too faint to show well and is represented better in another
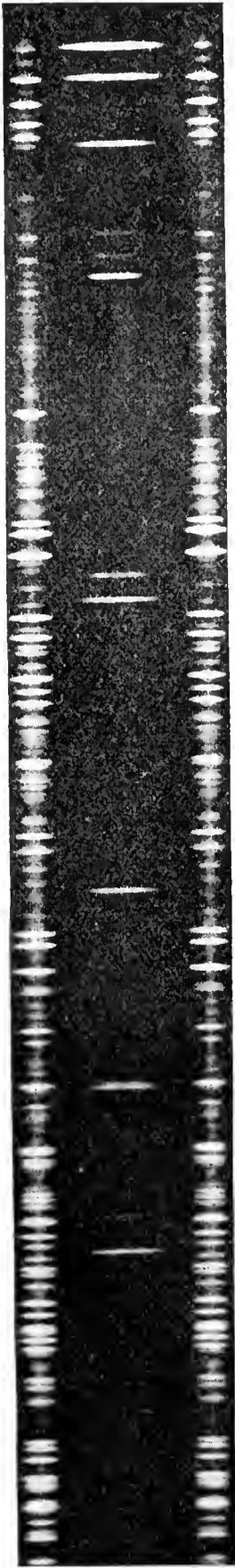
Fig. 5.
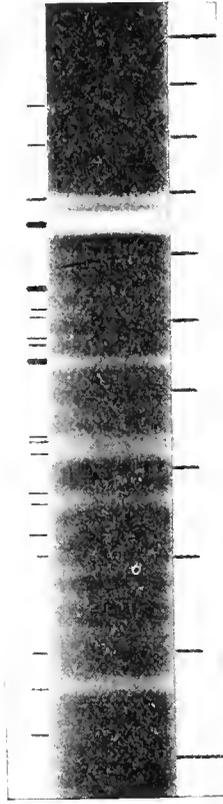
Fig. 6.

Fig. 7.

Fig. 8.

object (N. G. C. No. 40), which has a central condensation of exceptional strength, Fig. 6. The somewhat lumpy look of its continuous spectrum is due to the presence of emission bands. It will be noted that the positions of these bands do not correspond with those of the narrow nebular lines. It is a somewhat peculiar fact that the spectrum of a nebula and its nucleus differ markedly from each other. The photograph was made to show the narrow nebular lines, and the continuous spectrum is overexposed, but another record, Fig. 7, enlarged by means of a cylindrical lens, is more legible. The dots above the spectrum indicate the positions of the brighter emission bands of the Class O or Wolf-Rayet stars. The correspondence is complete, and the neucleus of the nebula is to be regarded as a star of that group. Fig. 8 shows the spectrum of another system of which the nucleus is extremely bright. The narrow lines belong to the nebula, while the hazy bands constitute the spectrum of the nucleus. The object was originally catalogued as a Class O star, and the surrounding nebulosity was found later. It is Campbell's so called *hydrogen envelope star,* in reality a planetary nebula.

Examples such as these might be multiplied, but there is no occasion for the repetition. Summarizing the results for all of the nebulæ observed, we have:

1. Of the forty-seven nebulæ examined thirty have nuclei sufficiently bright for their spectra to be photographed.

2. Of these thirty nuclei fifteen are Class O stars, and all show spectra indicative of high temperature.

I believe that upon this showing all of the nebular nuclei are to be regarded as belonging to the same general group as the Class O stars. When we recall that throughout the sky only one star in several thousand is known to belong to that group, it is difficult to escape the conclusion that there is an intimate connection between them and the nebulæ. The table summarises the argument in favor of such a connection; there are:

1. Nebulæ without nuclei.

2. Nebulæ with nuclei. The nuclei are in all instances stars of very high temperature, and in half of the cases show Class O bands.

3. Class O stars, with no (observed) nebulous surroundings. Temperature high.

In a single instance a star, previously described as belong to Class O, has been found to be surrounded by a planetary nebula, and it appears likely that other observations of a similar character will be made in the future, but such discoveries are hardly necessary to add to the proof of the connection. The only effect would be to remove one or more objects from group 3 and place them in group 2. In considering this relationship it should be borne in mind that the nebulæ and the Class O stars have comparatively few points of spectral correspondence, either in wave-length or in character of line, but the *nebular nuclei* are Class O stars, and while their spectra differ from the spectra of their surrounding nebulosities, we have here the undoubted proof of *physical association* to bridge the gap in spectral similarity.

Reverting now to the hypothesis diagram of figure 2, this spectral relationship may be interpreted in various ways:

1. It may be taken as fortifying the hypothesis diagramed on the left and refuting the other.

2. The planetary nebulæ may be regarded as not standing in the prior relationship to the stars indicated in both diagrams, but as representing a development later in life.

3. They may be bodies exceptional character, not directly related to those in the supposed ordinary scheme of development.

While the evidence appears to favor the first there are arguments for and against all of these interpretations, but there is no occasion to discuss them here. If I have indicated at considerable length the possible bearing of the observations on present notions of stellar evolution it has been to point out the critical nature of nebular relationships rather than to attempt to bolster any particular theory. What is regarded as a definite outcome of the work is that it helps to perfect the proof of an element of stellar classification: the relationship of the planetary nebulæ to the Class O stars.

As bearing on the physical conditions obtaining in the planetary nebulæ which we find associated with these extremely hot, or elec-

trically active stars, attention may be directed to a rather remarkable continuous spectrum which begins near the limit of the Balmer series of hydrogen and extends toward the ultra-violet. The spectrum may be seen in the photograph (Fig. 9) as a broad, faint band
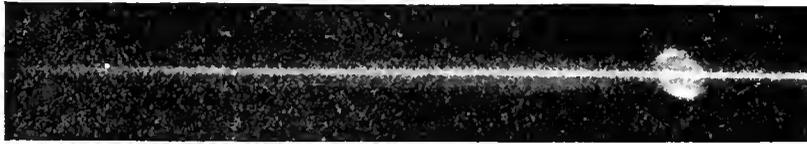
FIG. 9.

lying to the left of the strong negular image.[5] A similar phenomenon has been observed by Evershed in the solar chromosphere. The spectrum is assumed to be due to hydrogen, though nothing of the sort has been found, with certainty, in the laboratory. It is perhaps significant that a spectrum would be expected there if we accept the Bohr atomic theory. From the atomic model which Bohr sets up, the Balmer line series of hydrogen develops from the recovery of a partially separated electron, while an extension of his equations to include the capture of free electrons by positive nuclei establishes a continuous spectrum at just this place. I must confess that I venture into the domain of the physicist with trepidation, and I have, for the purposes of this small excursion, sought the hospitable protection and guidance of Professor Millikan, which have been generously accorded. Professor Millikan has pointed out that the justification of this interpretation would depend upon the ratio of the energy of agitation of the electron to the energy expended in capture, that is to Planck's constant multiplied by the frequency of vibration at the limit of the Balmer series. A temperature of about 6000° centigrade would afford the requisite amount of kinetic energy. As a matter of fact that is about the temperature of the solar chromosphere, which, as we have seen, also emits this spectrum. It will be recalled in this connection that Buisson, Fabry, and Bourget have estimated the temperature of the Orion Nebula to be about 15000° Cent. It seems equally possible that the electronic

[5] This illustration, unlike the others, shows a spectrum recorded with a "slitless" spectograph. For this reason a bright line is represented by an image of the nebula, instead of by a narrow line, as in the other illustrations.

energy requisite for the production of this spectrum might be provided by an electric field. Interpreted through the medium of Bohr's very convenient, but equally myterious conception, this continuous spectrum indicates for the planetary nebulæ themselves a degree of temperature, or electrical excitation, comparable with that found to exist in their nuclei, and in other intensely radiating stars.

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1921

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IT WILL AWARD ITS

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TO THE AUTHOR OF THE BEST DISCOVERY, OR MOST USEFUL INVENTION, RE-LATING TO NAVIGATION, ASTRONOMY, OR NATURAL PHILOSOPHY (MERE NATURAL HISTORY ONLY EXCEPTED) UNDER THE FOLLOWING CONDITIONS :

1. The candidate shall, on or before November 1, 1921, deliver free of postage or other charges, his discovery, invention or improvement, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A., and shall distinguish his performance by some motto, device, or other signature. With his discovery, invention, or improvement, he shall also send a sealed letter containing the same motto, device, or other sig-nature, and subscribed with the real name and place of residence of the author.

2. Persons of any nation, sect or denomination whatever, shall be ad-mitted as candidates for this premium.

3. No discovery, invention or improvement shall be entitled to this premium which hath been already published, or for which the author hath been publicly rewarded elsewhere.

4. The candidate shall communicate his discovery, invention or improvement, either in the English, French, German, or Latin language.

5. A full account of the crowned subject shall be published by the Society, as soon as may be after the adjudication, either in a separate publication, or in the next succeeding volume of their Transactions, or in both.

6. The premium shall consist of an oval plate of solid standard gold of the value of ten guineas, suitably inscribed, with the seal of the Society annexed to the medal by a ribbon.

All correspondence in relation hereto should be addressed

To THE SECRETARIES OF THE

AMERICAN PHILOSOPHICAL SOCIETY

No. 104 SOUTH FIFTH STREET

PHILADELPHIA, U. S. A.

MINUTES.

MINUTES.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The decease was announced of

Charles E. Hall, on October 21, 1915.

Louis Valentine Pirrson, M.A., at New Haven, on December 8, 1919, æt. 59.

Sir William Osler, Bart., at Oxford, England, on December 29, 1919, æt. 70.

C. E. K. Mees, D.Sc., read a paper on " Photography from the Air. An account of Technical Conditions which are met in Aërial Photography and of the Methods by which they have been Studied," which was discussed by Dr. Ives, Mr. Rosengarten, and the President.

The Judges of the Annual Election held this day between the hours of 2 and 5 in the afternoon, reported that the following named members were elected according to the rules, regulations and ordinances of the Society, to be the Officers for the ensuing year.

President.

William B. Scott.

Vice-Presidents.

George Ellery Hale,
Arthur A. Noyes,
Hampton L. Carson.

Secretaries.

I. Minis Hays,
Arthur W. Goodspeed,
Harry F. Keller,
John A. Miller.

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iv   MINUTES.

Curators.

William P. Wilson,
Leslie W. Miller,
Henry H. Donaldson.

Treasurer.

Henry La Barre Jayne.

Councillors.

(To serve for three years.)

William Libbey,
W. W. Atterbury,
M. I. Pupin,
Morris Jastrow, Jr.

(To fill an unexpired term in the

Class of 1918–20.)
Edwin Swift Balch.

Stated Meeting, February 6, 1920.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The decease was announced of Richard C. Maclaurin, D.Sc., LL.D., at Boston, on January 15, 1920, æt. 50.

Dr. Louis A. Bauer read a paper on " Observations in Liberia and elsewhere of the Total Solar Eclipse of May 29, 1919, and their bearing upon the Einstein Theory " (illustrated by a complete series of lantern slides from all observations, showing the finely developed solar corona and remarkable prominence as well as the deflected star images), which was discussed by Professor J. A. Miller and Dr. Bauer.

Stated Meeting, March 5, 1920.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

Prof. Edward W. Berry, a recently elected member, subscribed the Laws and was admitted into the Society.

Letters were received from Prof. John Trowbridge and Prof. W. LeConte Stevens, resigning membership.

The decease was announced of Francis C. Phillips, Ph.D., at Pittsburgh, on February 16, 1920, æt. 69.

The following papers were read:

"Across the Andes in Search of Fossil Plants," by E. W. Berry, which was discussed by Prof. Harshberger and Dr. Scott.

"Interrelations of Fossil Fuels—The Paleozoic Coals," by John J. Stevenson, Ph.D., LL.D.

Special Meeting, March 31, 1920.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The resignation of Dr. W. H. Holmes was presented.

The decease was announced of Wilhelm F. Pfeffer, M.D., D.Sc., at Leipzig, on January 31, 1920, æt. 75.

Mr. Howard Russell Butler, of Princeton, read a paper entitled "Painting the Solar Eclipse of 1918," which was discussed by Prof. L. W. Miller and Mr. H. S. Morris.

Stated General Meeting, April 22, 23, and 24, 1920.

Thursday Afternoon, April 22.

Opening Session, 2 o'clock.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

Dr. Chevalier Jackson, a recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Beach Protection Works," by Lewis M. Haupt, Sc.D., LL.D., which was discussed by Professors Prince and Webster.

"Geographic Aspects of the Adriatic Problem," by Douglas W. Johnson, Professor of Hydrography at Columbia University (introduced by Prof. W. M. Davis), which was discussed by President Scott and Prof. A. G. Webster.

"The Reefs of Tutuila, Samoa, in their Relation to Coral Reef Theories," by Alfred G. Mayor, Director of the Department of Marine Biology, Carnegie Institution of Washington.

"Distribution of Land and Water on the Earth," by Harry Fielding Reid, C.E., Ph.D., Professor of Dynamic Geology,

Johns Hopkins University, which was discussed by Prof. W.
M. Davis and Prof. A. G. Webster.

"Thyroxin," by C. E. Kendall, Ph.D., of the Mayo Clinic, As-
sistant Professor of Chemistry, University of Minnesota
(introduced by Dr. P. B. Hawk), which was discussed by Dr.
Keen.

"The Dualistic Conception of the Processes of Life," by Sam-
uel J. Meltzer, M.D., LL.D., Head of Dept. of Physiology,
Rockefeller Institute for Medical Research, New York.

"The Relation of the Bacillus Influenzæ to Influenza," by
Francis G. Blake, M.D., Associate in Medicine, Hospital of
the Rockefeller Institute for Medical Research, New York.
(Introduced by Dr. A. C. Abbot.)

"X-Rays of the Brain after Injection of Air into the Ven-
tricles of the Brain and into the Spinal Canal," by W. E.
Dandy, M.D., Associate in Surgery, Johns Hopkins Hospital
(introduced by Dr. Keen), which was discussed by Dr. Keen.

"Celt and Slav," by J. Dyneley Prince, Ph.D., Professor of
Slavonic Languages, Columbia University, which was dis-
cussed by Professors Jastrow, W. M. Davis, A. G. Webster,
W. E. Castle, J. D. Prince and President Scott.

"A New Theory of Polynesian Origins," by Roland B. Dixon,
Ph.D., Professor of Anthropology, Harvard University.
(Introduced by W. C. Farabee.)

"The Zoroastrian Doctrine of the Freedom of the Will," by A.
V. Williams Jackson, L.H.D., LL.D., Professor of Indo-
Iranian Languages, Columbia University.

"The Hittite Civilization," by Morris Jastrow, Jr., Ph.D.,
LL.D., Professor of Semitic Languages, University of Penn-
sylvania, which was discussed by Prof. A. G. Webster.

Friday, April 23.

Executive Session, 9:30 o'clock.

The Proceedings of the Officers and Council were submitted.

Morning Session, 10 o'clock.

ARTHUR A. NOYES, D.Sc., LL.D., Vice-President, in the Chair.
The following papers were read:

"The Components and Colloidal Behavior of Protoplasm," by D. T. MacDougal, Ph.D., LL.D., Director of the Desert Laboratory, Carnegie Institution, Tucson, Arizona, and H. A. Spoehr.

"Respiration," by W. J. V. Osterhout, Professor of Botany, Harvard University.

"The Behavior of the Sulfurea Character in Crosses with *Œnothera biennis* and with *Œnothera franciscana*," by Bradley M. Davis, Professor of Botany, University of Michigan, which was discussed by Professors Geo. H. Shull and A. G. Webster.

"*Œnothera funifolia*, a peculiar new Mutant from *Œnothera lamarckiana*," and

"A Third Duplication of Genetic Factors in Shepherd's Purse," by George H. Shull, Ph.D., Professor of Botany and Genetics, Princeton University, which was discussed by Professors W. E. Castle and A. G. Webster.

"Some Effects of the Fertilization of Maize," by Edward M. East, Ph.D., Professor of Experimental Plant Morphology, Harvard University.

"The Chemistry of the Cell," by Thomas B. Osborne, Ph.D., D.Sc., Research Chemist Connecticut Agricultural Experiment Station. (Introduced by Dr. Harry F. Keller.)

"The Relation of Oxygen to Charcoal," by George A. Hulett, Ph.D., Professor of Physical Chemistry, Princeton University.

"Products of Detonation of TNT," by Charles E. Munroe, Ph.D., LL.D., Professor of Chemistry, George Washington University and S. P. Howell, which was discussed by Prof. A. G. Webster.

"A New Map of the Vegetation of North America," by John W. Harshberger, Ph.D., Professor of Botany, University of Pennsylvania, which was discussed by Dr. MacDougal and President Scott.

"On the Vibration of Rifle Barrels," by Arthur Gordon Webster, D.Sc., LL.D., Professor of Physics, Clark University, Worcester.

Afternoon Session, 2 o'clock.

HAMPTON L. CARSON, M.A., LL.D., Vice-President, in the Chair.

Professors Stephen A. Forbes, Dayton C. Miller, Henry A. Bumstead and Julius Stieglitz, recently elected members, subscribed the Laws and were admitted into the Society.

The following papers were read:

Symposium on Psychology in War and Education
    "Introduction," by Lightner Witmer, Ph.D., Director of the Psychological Laboratory and Clinic, University of Pennsylvania.
    "Methods," by J. McKeen Cattell.
    "Psychological Examining and Classification in the United States Army," by Robert M. Yerkes, Ph.D., Chairman of Division of Research Information, National Research Council, Washington. (By invitation.)
    "The Relation of Psychology to Special Problems of the Army and Navy," by Raymond Dodge, Ph.D., Professor of Psychology, Wesleyan University. (By invitation.)
    "Relation of Psychology to the National Research Council," by James R. Angell, A.M., Litt.D., Chairman of the National Research Council, Washington. (By invitation.)
    "Psychological Methods in Business and Industry," by Beardsley Ruml, Ph.D., Philadelphia. (By invitation.)
    "The Individual in Education," by Arthur J. Jones, Ph.D., Professor of Education, University of Pennsylvania. (By invitation.)
    which were discussed by Prof. Webster and Mr. Carson.

Evening Session, 8: 30 o'clock.

Robert William Wood, LL.D., Professor of Experimental Physics, Johns Hopkins University, spoke on "Invisible Light in War and Peace" (with experimental illustrations).

Saturday, April 24.

Executive Session, 9:30 o'clock.

William B. Scott, D.Sc., LL.D., President, in the Chair.

Prof. Carl Eigenmann and William A. Setchell, recently elected members, subscribed the Laws and were admitted into the Society.

Pending nominations for membership were read and the Society proceeded to an election. The tellers subsequently reported that the following nominees had been elected to membership, viz.:

Wilder D. Bancroft, Ph.D., Washington.
Gary N. Calkins, Ph.D., New York.
Edward Capps, Ph.D., LL.D., Princeton.
Heber D. Curtis, A.M., Ph.D., Mt. Hamilton, Calif.
Leonard E. Dickson, A.M., Ph.D., Chicago.
William Duane, A.M., Ph.D., Boston.
Moses Gomberg, M.S., Sc.D., Ann Arbor.
Frank J. Goodnow, A.M., LL.D., Baltimore.
John F. Jameson, Ph.D., LL.D., Litt.D., Washington.
Douglas W. Johnson, Ph.D., New York.
Vernon L. Kellogg, M.S., Stanford Univ., Calif.
George F. Moore, A.M., LL.D., D.D., Cambridge.
Paul Shorey, LL.D., Litt.D., Chicago.
William C. Sproul, B.S., Ph.D., Chester, Pa.
Pope Yeatman, M.E., Philadelphia.

The following recommendation from the Officers and Council was considered and adopted by unanimous vote:

"That nominations for membership of persons not inhabitants of the United States be suspended until the number of such members be reduced to fifty and that thereafter the number of such members shall not exceed fifty."

Morning Session, 10 o'clock.

George Ellery Hale, Ph.D., Sc.D., Vice-President, in the Chair.

The following papers were read:

"The Problem of the Evolution of the Solar System," by

Ernest W. Brown, Sc.D., Professor of Mathematics, Yale University, which was discussed by Professors Geo. E. Hale, A. G. Webster, W. M. Davis and H. N. Russell.

" Certain Aspects of recent Spectroscopic Observations of the Gaseous Nebulæ which appear to Establish the relationship between them and the Stars," by W. H. Wright, Astronomer, Lick Observatory (introduced by Prof. Robert G. Aitken), which was discussed by Professors H. N. Russell and M. B. Snyder.

" The Einstein Theory," by Edwin Plimpton Adams, Ph.D., Professor of Physics, Princeton University, which was discussed by Professors A. G. Webster and Elihu Thomson.

" The Results of Geophysical Observations during the Solar Eclipse of May 29, 1919, and their Bearing upon the Einstein Deflection of Light " (illustrated), by Louis A. Bauer, Ph.D., Sc.D., Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, which was discussed by Professors H. N. Russell, J. A. Miller and George E. Hale.

" The High Voltage Corona in Air," by J. B. Whitehead, Professor of Applied Electricity, Johns Hopkins University (introduced by Dr. Pender), which was discussed by Prof. Elihu Thomson.

" The Velocity of Explosive Sounds," by Dayton C. Miller, D.Sc., Professor of Physics, Case School of Applied Science, Cleveland, which was discussed by Professors A. G. Webster, Harvey W. Wiley and Augustus Trowbridge.

" The U. S. Navy MV-Type of Hydrophone as an aid and safeguard to Navigation," by Harvey C. Hayes, Ph.D., U. S. Naval Experimental Station, Annapolis (introduced by Dr. John A. Miller), which was discussed by Prof. Webster.

" The Transient Process of Establishing a steady Alternating Electric Current on a long line from Laboratory Measurements on an artificial Line," by A. E. Kennelly, A.M., Sc.D., Director, Research Division, Electrical Engineering Department, Mass. Institute of Technology, and U. Nabeshima, which was discussed by Prof. A. G. Webster.

Afternoon Session, 2 o'clock.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

The presentation of a portrait of the late Edward C. Pickering, LL.D., Vice-President of the Society, 1909–17, was made, on behalf of the donors, by Dr. George E. Hale, and the gift was received with thanks by the President.

Prof. J. C. Merriam, a recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Animal Luminescence and Stimulation," by E. Newton Harvey, Ph.D., Professor of Physiology, Princeton University. (Introduced by Dr. H. H. Donaldson.)

"The Phosphorescence of Renilla," by George H. Parker, S.D., Professor of Zoölogy, Harvard University, which was discussed by Prof. Eric Dahlgren.

"Feeding Habits of Pseudomyrmine Ants," by W. M. Wheeler, Ph.D., Sc.D., Professor of Economic Entomology, Bussey Institution, Harvard University, and Irving W. Bailey, Assistant Professor of Forestry, Harvard University, which was discussed by Prof. Kennelly.

"On Correlation of Shape and Station in Fresh Water Mussels," by A. E. Ortmann, Ph.D., Sc.D., Curator of Invertebrate Zoölogy, Carnegie Museum, Pittsburgh.

"Evolution Principles deduced from a Study of the Even-toed Ungulates, known as Titanotheres," by Henry Fairfield Osborn, Sc.D., LL.D., Research Professor of Zoölogy, Columbia University.

"The Astrapotheria," by William B. Scott, Sc.D., LL.D., Professor of Geology, Princeton University.

"The Middle Cambrian Beds at Manuels, Newfoundland, and their Relations," by B. F. Howell, Jr., B.S., Instructor in Geology, Princeton Univ. (Introduced by Prof. W. B. Scott.)

"The Glacial Anticyclone and the Blizzard in Relation to the Domed Surface of Continental Glaciers," by William H.

Hobbs, D.Sc., Ph.D., Professor of Geology, University of Michigan, which was discussed by Prof. W. M. Davis.

Also

"The Michigan Meteor of November 26, 1919," by the same author, which was discussed by Professors A. G. Webster, Elihu Thomson, W. F. Magie and H. N. Russell.

"The Decipherment of the Hittite Languages," by Maurice Bloomfield, L.H.D., LL.D., Professor of Sanskrit and Comparative Philology, Johns Hopkins University, which was discussed by Professors Jastrow and Paul Haupt.

(1) The Beginning of the Fourth Gospel.

(2) "Golgotha," by Paul Haupt, Ph.D., LL.D., Professor of Semitic Languages, Johns Hopkins University, which were discussed by Professors Webster and Jastrow.

"The Strephoscope," by N. W. Akimoff. (Introduced by Prof. Eric Doolittle.)

"New Features in the Eclipsing Variable U Cephei," by R. S. Dugan, Professor of Astronomy, Princeton University. (Introduced by Prof. H. N. Russell.)

"Universal Radioaction and the Volcanoes," by John A. Snyder, Professor of Astronomy and Mathematics, Central High School, Philadelphia, and Monroe B. Synder, Director of the Philadelphia Observatory.

Stated Meeting, May 7, 1920.

WILLIAM B. SCOTT, D.Sc., LL.D., President, in the Chair.

Mr. Pope Yeatman, a newly elected member, subscribed the Laws and was admitted into the Society.

Letters accepting membership were received from:

Wilder D. Bancroft, Ph.D.,

Edward Capps, Ph.D.,

Leonard E. Dickson, A.M., Ph.D.,

William Duane, Ph.D.,

Moses Gomberg, M.S., Sc.D.,

Frank J. Goodnow, A.M., LL.D.,

John F. Jameson, Ph.D., LL.D.,

Douglas W. Johnson, Ph.D.,

Vernon L. Kellogg, M.S.,

Pope Yeatman, M.E.

The decease was announced of John A. Brashear, D.Sc., LL.D., at Pittsburgh, on April 8, 1920, æt. 80.

Prof. Charles Upson Clark read a paper on "The Adriatic Problems."

Special Meeting, May 14, 1920.

HAMPTON L. CARSON, M.A., LL.D., Vice-President, in the Chair.

The meeting was called by the President to take action on the death of Henry La Barre Jayne, the Treasurer of the Society.

The decease was announced of Henry La Barre Jayne, at Philadelphia, on May 10, 1920, æt. 62.

The following minute was offered:

" This Society has learned with genuine grief of the death of Henry La Barre Jayne. The twenty-two years of his membership were characterized by an earnest loyalty to its interests, a constant solicitude for its welfare and an eager desire at all times to do everything within his power to promote its usefulness. For eighteen years he discharged the duties of Treasurer with marked fidelity. By his lovable traits, his benevolent character, his unfailing courtesy, his rare amiability and his high sense of justice, he commanded the esteem and admiration of all whose privilege it was to know him.

" This Society desires to record its deep appreciation of the valuable services which he rendered to it both as a member and as its Treasurer, and its high estimate of his notable qualities of mind and heart which greatly endeared him to his associates."

The adoption of the foregoing minute was moved, with appropriate remarks, by Mr. Russell Duane, Dr. W. W. Keen, Dr. Morris Jastrow, Jr., Mr. Rosengarten and Vice-President Carson.

The minute was adopted by an unanimous vote.

Stated Meeting, October 1, 1920.

William B. Scott, Sc.D., LL.D., President, in the Chair.

Hon. William C. Sproul, a newly elected member, subscribed the Laws and was admitted into the Society.

Letters accepting membership were received from

The Hon. William C. Sproul,

Prof. Paul Shorey,

Prof. George F. Moore,

Mr. Heber D. Curtis,

Prof. Gary N. Calkins.

The decease was announced of the following members:

Gen. William C. Gorgas, M.D., at London, on July 4, 1920, æt. 66.

William H. Furness, 3d, M.D., at Wallingford, Pa., on August 11, 1920, æt. 54.

Benjamin Smith Lyman, at Philadelphia, on August 30, 1920, æt. 88.

William Wundt, Ph.D., at Leipzig, on Aug. 31, 1920, æt. 88.

Harmon N. Morse, Ph.D., at Chebeague, Maine, on Sept. 21, 1920, æt. 72.

Eric Doolittle, C.E., at Philadelphia, on Sept. 21, 1920, æt. 50.

Theodore Turrettini, of Geneva.

Prof. John M. Macfarlane made some verbal remarks on a recently discovered species of Philippine Nepenthes or Pitcher Plants, which was discussed by Mr. Rosengarten, Dr. Harshberger, Prof. True, and the President.

Dr. Harshberger made some remarks on a visit to the Box Huckleberry, *Gaylusaccia Brachycera,* at New Bloomfield, Perry County, Pa.

Stated Meeting, November 5, 1920.

William B. Scott, Sc.D., LL.D., President, in the Chair.

The decease was announced of

Joseph P. Iddings, Ph.D., Sc.D., at Brinklow, Md., on Sept. 8, 1920, æt. 63.

Prof. Yves Delage, at Roscoff, France, on Oct. 8, 1920, æt. 66.

Prof. Scott read a paper on the "Astrapotheria, a Remarkable Group of Prehistoric South American Animals."

Stated Meeting, December 3, 1920.

WILLIAM B. SCOTT, Sc.D., LL.D., President, in the Chair.

The decease was announced ot
Samuel James Meltzer, of New York, on November 7, 1920, æt. 69.

Baron de Geer, of Stockholm, spoke on "Spitzbergen as the Key to the Origin of Northern Europe and North America and the Starting of an Exact Geo-chronology."

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Date Due